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ULTRA SHORT BASELINE (USBL) CALIBRATION FOR POSITIONING OF UNDERWATER OBJECTS

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Abstrak

Pada umumnya, survey penentuan posisi mengunakan sistem satelit navigasi global. Satelit tersebut secara kontinyu mengirimkan sinyal radio ke permukaan bumi dan dideteksi oleh sensor penerima menjadi fungsi posisi dan waktu. Gelombang radio tidak baik menjalar pada medium air, sehingga pada penentuan posisi bawah laut menggunakan gelombang akustik. Salah satu jenis penentuan posisi bawah laut adalah USBL. USBL merupakan sistem penentuan posisi yang berdasarkan pada pengukuran jarak dan sudut. Berdasarkan jarak dan sudut, maka posisi dari target dalam kordinat kartesian dapat dideteksi. Dalam Pelaksanaannya, efek pergerakan kapal menjadi salah satu faktor yang menentukan tingkat akurasi dari sistem USBL. Pergerakan kapal berupa *pitch, roll,* dan *orientation* yang tidak terdefinisi *receiver* menyebabkan posisi target mengalami penyimpangan dalam kordinat X, Y dan Z. Kalibrasi USBL dilakukan untuk mendefinisikan kesalahan sudut. Kalibrasi USBL dilakukan dengan dua metode. Pada kalibrasi USBL statis *Single Position* diperoleh nilai koreksi *orientation* sebesar 1.13˚dan *scale factor* 0.99025. Untuk kalibrasi USBL *Quadrant* diperoleh nilai koreksi *pitch* sebesar -1.05˚, *Roll* -0.02˚, *Orientation* 6.82˚dan *scale factor* 0.9934. Hasil kalibrasi *Quadrant* mengurangi tingkat kesalahan posisi menjadi 0.276 – 0.289m pada kedalaman 89m dan 0.432m – 0.644m pada kedalaman 76m

Kata Kunci*: Penentuan Posisi, Kalibrasi USBL, Metode Single Position, Metode Quadrant.*

Abstract

In general, surface positioning using a global satellite navigation system (GNSS). Many satellites transmit radio signals to the surface of the earth and it was detected by receiver sensors into a function of position and time. Radio waves really bad when spreading in water. So, the underwater positioning uses acoustic wave. One type of underwater positioning is USBL. USBL is a positioning system based on measuring the distance and angle. Based on distance and angle, the position of the target in cartesian coordinates can be calculated. In practice, the effect of ship movement is one of the factors that determine the accuracy of the USBL system. Ship movements like a pitch, roll, and orientation that are not defined by the receiver could changes the position of the target in X, Y and Z coordinates. USBL calibration is performed to detect an error angle. USBL calibration is done by two methods. In USBL calibration Single Position obtained orientation correction value is 1.13˚and a scale factor is 0.99025. For USBL Quadrant calibration, pitch correction values is -1.05, Roll -0.02˚; Orientation 6.82˚and scale factor 0.9934 are obtained. The quadrant calibration results deccrease the level of error position to 0.276 - 0.289m at a depth of 89m and 0.432m - 0.644m at a depth of 76m

Keywords*: Positioning, USBL Callibration, Single Position Method, Quadrant Method*

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INTRODUCTION

In general, the positioning system is based on the Global Navigation Satellite System (GNSS). One type of GNSS is GPS. GPS is a satellite navigation system that belongs to the United States. GPS is operated on 24 satellites that are constantly orbiting the earth. This satellite is equipped with an atomic clock and sends radio signals to the earth as a function of time and location for GPS receivers [1]. GPS using radio signals. Radio signals can propagate well in the air, but not well in the water. This is because radio waves will spreading and arbsorption by the water, so that they can only propagate very short distances. Therefore, in underwater positioning, GPS technology is less than optimal for use. So, in a marine survey (offshore), positioning using an acoustic wave propagation. This is because acoustic wave can propagate well in the water [2]. The underwater positioning are used for underwater works such as oil and gas, offshore construction activities (offshore), rescue aircraft crash operations, and marine archeology [3]

The Underwater positioning system consists of several methods, namely Long Baseline (LBL), Short Baseline (SBL), and Ultra Short Baseline (USBL) [4]. In this research, I'm using an USBL method. The advantage of the USBL method is that the installation process is relatively easy because it does not require too many instruments so operational costs are not too high [5]. The USBL is a method of underwater positioning using two main instruments namely the transducer and transponder.

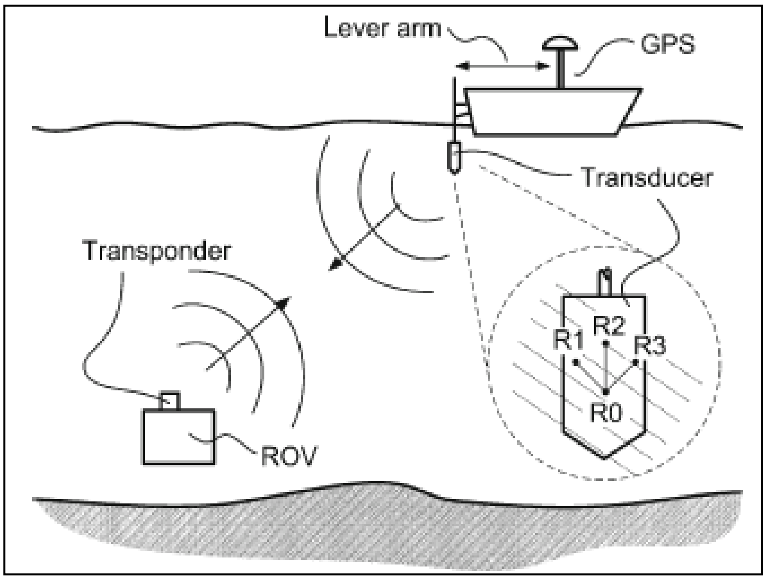


Figure 1. Ultra Short Baseline (USBL) Method

In principle, the transducer is installed under the draft of the ship which functions to emit acoustic waves under the sea and receive it back after reflecting from the transponder. Transponders installed on survey objects or tools such as ROV and Towfish that want to know their position. The transponder functions is to receive and reflect the waves emitted by the transducer. If it is known that the sound wave propagation under the sea based on the Sound Velocity Profiller tool and the wave travel time until the transducer is received, the distance between the transducer and the transponder (slant range) can be known [6]. In addition to the distance parameter, the reflection wave angle parameter is an important factor in USBL. Error reading of the angle a few degrees will reduce the level of USBL accuracy. This is what causes the USBL system is not well used for the purposes of surveys in the deep sea, because the level of accuracy is not good. The incident wave angle at USBL is obtained based on the phase difference between some receiver elements in the transducer. Based on the distance (R) and angle (θ), the position in the X and Y coordinates will be obtained by transforming from the polar coordinates into the Cartesian coordinates

In its implementation, the effect of ship movements such as pitch, roll and orientation will affect the accuracy of the USBL. That is because, the transducer on USBL was installed using a large enough mechanical pipe, which was installed on the survey ship. Ideally, the pitch, roll and orientation values are 0˚during the transducer installation. Value 0˚in the installation process, used as an initial parameter when the positioning process is carried out. However, this situation will be very difficult to obtain due to sea conditions that are always undulating. To minimize positioning errors, the Motion Reference Unit (MRU) instrument is used to detect the effect of the ship's movement. After the installation of the MRU too, it turned out that there was still a large enough position error. In several studies related to USBL, to reduce the position error rate which is quite large, the USBL calibration process is carried out.

Jan Obderbeck in 1997 had conducted research related to USBL calibration in the deep ocean with a depth of about 2548 m. In that study, correction of angular errors caused position errors on USBL to decrease from 48 m to 14 m in the 5th iteration [7]. Li et al in 2013 found that an angle error of 1 "during USBL installation caused a position error of 1.7% for slant range [8] and Jinwu et al in 2018 found that an angle error of 2" during installation caused a position error of 35m for sea depth of 1000 m [9]. In another study, Yu Min and Hui Junyin in 2010 calibrated the transducer array and obtained position data that were close to the position based on GPS signals [10].

The main factors that affect the accuracy of the USBL position are system model errors, measurement errors of marine environment parameters, error of time delay measurements and installation errors of the transducer array [11]. Errors in installing transducer arrays are the main source of errors for USBL positioning systems, and must be corrected accurately before they are used in survey activities [12]. Calibration of installation error of acoustic array USBL can be done by defining the effect of the movement of ships at sea [7]. In this study, focused on the effect of USBL calibration in the form of the effect of the ship's movement on the level of accuracy in the positioning system.

ULTRA SHORT BASELINE (USBL)

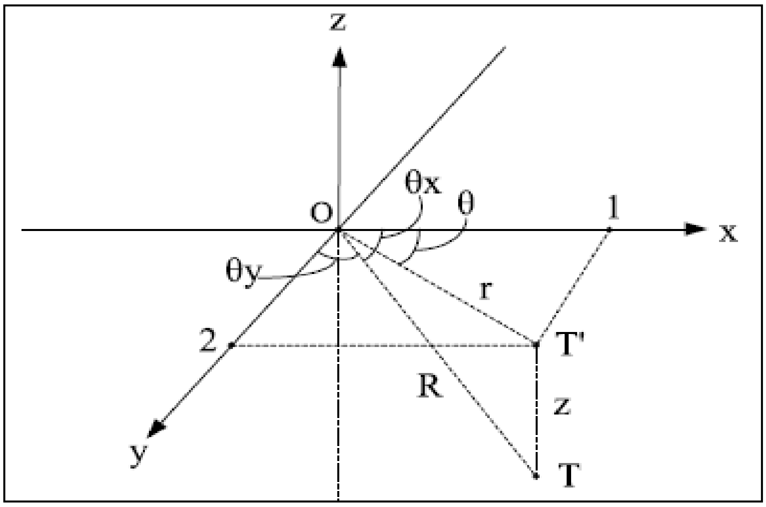


Figure 2. Scematics of USBL Positioning System [9]

In fig. 2 explained that O is the transducer position, T is the transponder position, T ’is the projection of the transponder position in the horizontal plane, θx is the angle between the X coordinate and the transponder distance (R) and θy is the angle between the Y coordinate and the transponder distance (R). The cos cos angle θx, cos θy and θ can be determined based on the cosine equation below.

$$\cos\theta\, x = \frac{x}{R} \tag{1}$$

$$\cos\theta\, y = \frac{y}{R} \tag{2}$$

$$\theta = arc\ tan\frac{y}{x} \tag{3}$$

Where θ is the angle formed between the X coordinate and the transponder position in the horizontal projection (T ’). While x is the position in coordinate X and y is the position in coordinate Y, so that from the Eq. (2) and Eq. (3), the transponder location can be determined based on X coordinates and Y coordinates through the Eq. (4) and Eq. (5).

$$x = R\ \cos\theta x \tag{4}$$

$$y = R\ \cos\theta \mathrm{y} \tag{5}$$

R is the distance between the sensor element on the transducer and the transponder. The vector T coordinate on the transponder is \ bar {OT}, so the distance R from the transponder T to the original coordinate can be determined based on Eq. (6)

$$R = \sqrt{X^2 + Y^2 + Z^2} \tag{6}$$

In addition to the distance of the transducer to the actual position of the transponder, there is also r which is the distance between the transducer to the projected position of the transponder in the horizontal plane. Based on the Pythagorean theorem, the distance r can be determined based on Eq. (7). In addition, by substituting the Eq. (7) into the Eq. (6), then the depth of the transponder symbolized by Z can be determined through the Eq. (8)

$$r = \sqrt{x^2 + y^2} \tag{7}$$

$$z = \sqrt{R^2 - \ r^2} \tag{8}$$

However, operationally the value of R is determined based on the acoustic wave propagation time received by the transducer and the acoustic wave propagation speed under sea water. Where in this case, it is assumed that the acoustic wave velocity under sea water has a uniform value, so that the value of R can be determined according to Eq. (9)

$$R = \frac{C\ \Delta t}{2} \tag{9}$$

Where C is the acoustic wave propagation velocity under the sea (m / s) and Δt is the acoustic wave propagation time to the transducer. On USBL systems, the angle values cos θx and cos θy are obtained from the difference in wave phase received by the receiver element in the transducer. Where the receiver element is located at two different baselines. Receiver elements 1 and 3 are located in the X coordinate of the coordinate system in the USBL acoustic sensor element array. Receiver elements 2 and 4 are located in the Y coordinate of the coordinate system in the USBL acoustic sensor element array. For more details, can be seen in fig. 3. The phase difference of the signals received by receivers 1 and 3 can be defined according to Eq. (10) and the phase difference of the signals received by receivers 2 and 4 can be defined via Eq. (11)

$$\varphi 1.3 = \frac{2\pi d \cos\theta x}{\lambda} \tag{10}$$

$$\varphi 2.4 = \frac{2\pi d \cos\theta y}{\lambda} \tag{11}$$

Where φ1.3 is the phase difference between the two receiver elements in the X coordinate, φ2.4 is the phase difference between the two receiver elements in the Y and d coordinates is the distance between the two receiver elements at the baseline.

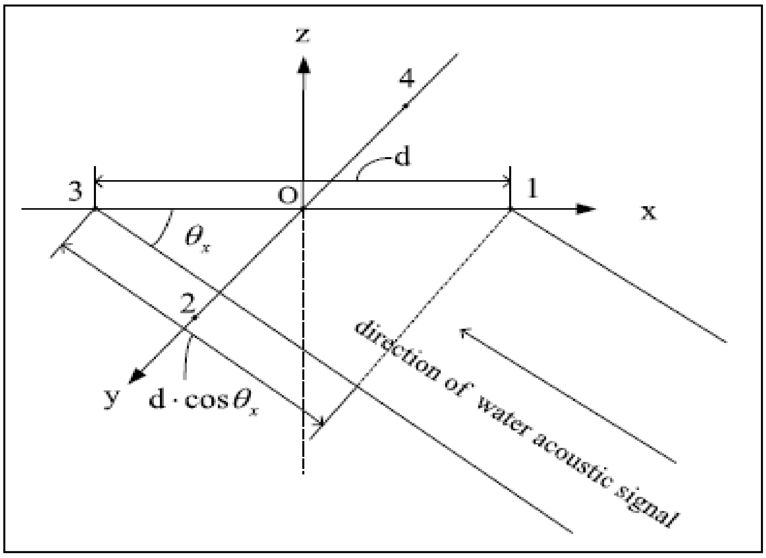


Figure 3 Phase Different Between Two Receiver Elements

Based on the phase difference obtained from the Eq. (10) and the Eq. (11), the angles θx and θy can be determined through Eq. (12) and the Eq. (13)

$$\cos\theta x = \frac{\lambda\,\varphi 1.3}{2\pi d} \tag{12}$$

$$\cos\theta y = \frac{\lambda\,\varphi 2.4}{2\pi d} \tag{13}$$

By substituting the Eq. (12) and the Eq. (13) into the Eq. (4) and Eq. (5), the values of the X coordinate and the Y coordinate of the transponder position can be determined by distance and bearing. While the Z coordinates can be calculated by substituting the Eq. (7) to the Eq. (8) to get the Eq. (16).

$$x = \frac{R\,\lambda\,\varphi 1.3}{2\pi d} \tag{14}$$

$$y = \frac{R\,\lambda\,\varphi 1.3}{2\pi d} \tag{15}$$

$$z = R\sqrt{1 - cos^2\theta x\ -\ cos^2\theta y} \tag{16}$$

Based on the Eq. (14), (15) and (16), the transponder position can be determined based on X coordinates, Y coordinates and Z coordinates.

$$Pt = \begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} \frac{R\,\lambda\,\varphi 1.3}{2\pi d} \\ \frac{R\,\lambda\,\varphi 1.3}{2\pi d} \\ R\sqrt{1 - cos^2\theta x\ -\ cos^2\theta y} \end{bmatrix} \tag{17}$$

METODOLOGY

In this research, the tools used for the USBL calibration process include a transducer and transponder unit, a set of Portable Fusion USBL System boxes consisting of 3 modules, namely the Navigation Controller Unit (NCU) module, a computer module and a monitor module, a set of starpack type GNSS to find out the absolute location of the survey ship, a compass gyro unit to determine the geographic north position of the earth. motion reference unit (MRU) to detect changes in the angle of the transducer, and PC unit equipped with Microsoft Excel, Starfix NG 2018, and WSM Terminal applications

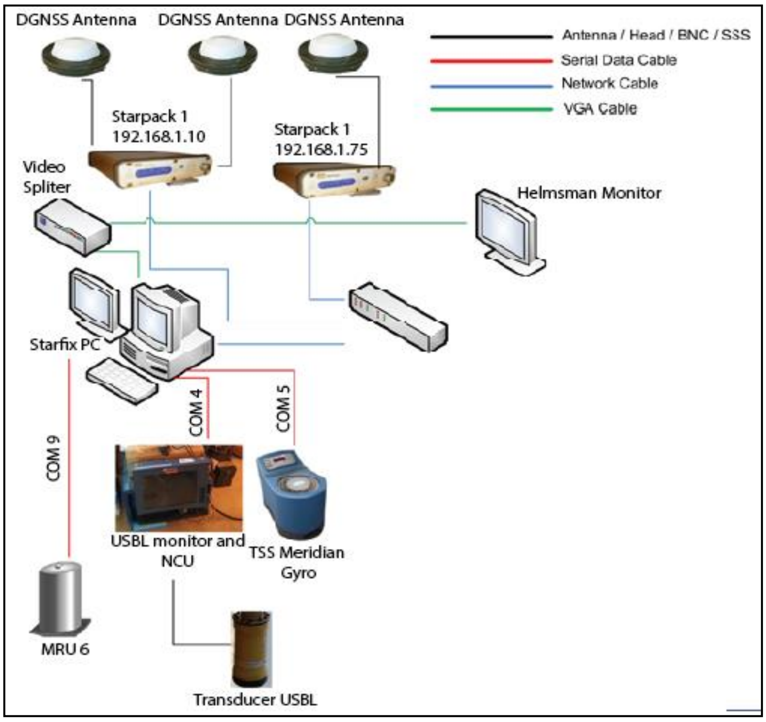


Figure 4. Desain Instalasi Alat Penelitian

This research begins with the installation of the tool as shown in Fig. 4. Then, conFigure tools using Starfix NG 2018 such as defining ship offsets, defining geodesy, defining sound wave propagation at sea and connecting all research instruments. If the parameters in the calibration have been entered and defined, the calibration process can be carried out. Furthermore, the results of USBL calibration in QC to see whether the calibration results are in accordance with needs or not through the USBL verification process. The verification process is carried out by entering the calibration value as a parameter of the angle of error in the operation of the USBL system

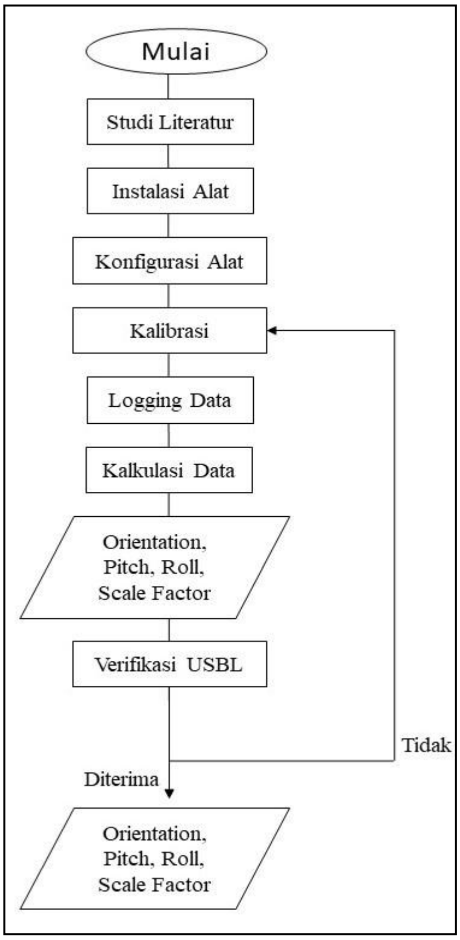


Figure 5. Flow Chart of This Research

In this paper, USBL calibration is carried out by two methods, namely the single position static method and the Quadrant / Box in method. USBL single position static calibration is located of Terengganu, Malaysia. The ship used in this calibration is a barge type. The transducer position is placed in the centre of starboard barge and two transponders are placed respectively in starboard bow and starboard stern of the barge. Furthermore, the Gyro compass is mounted on the ship and connected to the Navigation Control Unit (NCU) to determine the orientation position of the ship. After all equipment is ready, the data logging process is carried out.

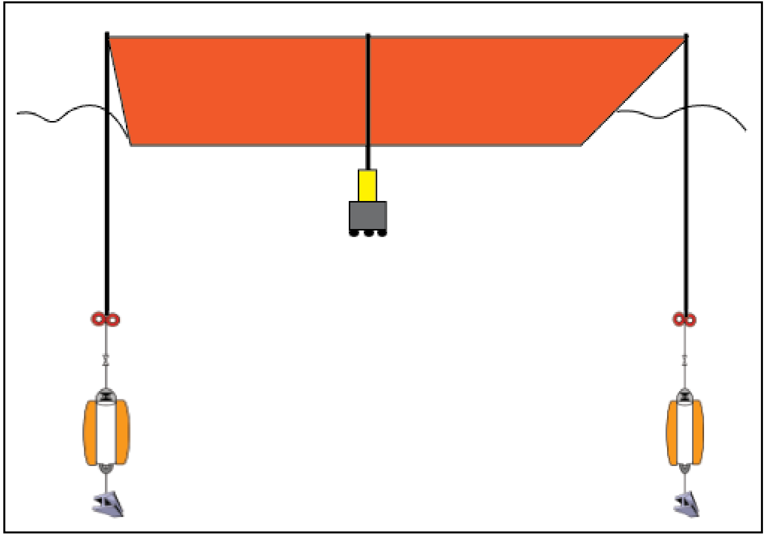


Figure 6. Schematic of Static Callibration

Quadrant / Box in calibration is located around Natuna Island, Indonesia. The ship used in this calibration process is Servewell Sincere. Based on Single Beam Echosounder data, the depth of the sea in the survey area is around 94 m. To find out the fast spread of sound propagation at sea, the Sound Velocity Profile (SVP) data was collected using the Sound Velocity Profiller type AML SVplus. The data will later be used as a quick reference wave propagation under the sea in the NCU module. Based on the calibration design, the transponder position is at coordinate 648519.305 S and 477390,781 N using UTM zone 48N projection and WGS 84 datum. To find out the effect of vessel and pitch movement, MRU instrument is used 6. The Gyro compass instrument is used to get orientation influence on vessels . According to the Quadrant / box in calibration procedure, the orientation position of the ship when logging data must be the same at each point. Determination of the orientation of the ship is based on the direction of the current and sea breeze so that the orientation is expected to be more stable. In this study, the orientation position of the ship is at 210˚. In addition, the angle between the calibration points must be at an angle of 90˚. For more details, can be seen in Fig. 6 which is a Quadrant / box in USBL static calibration design.

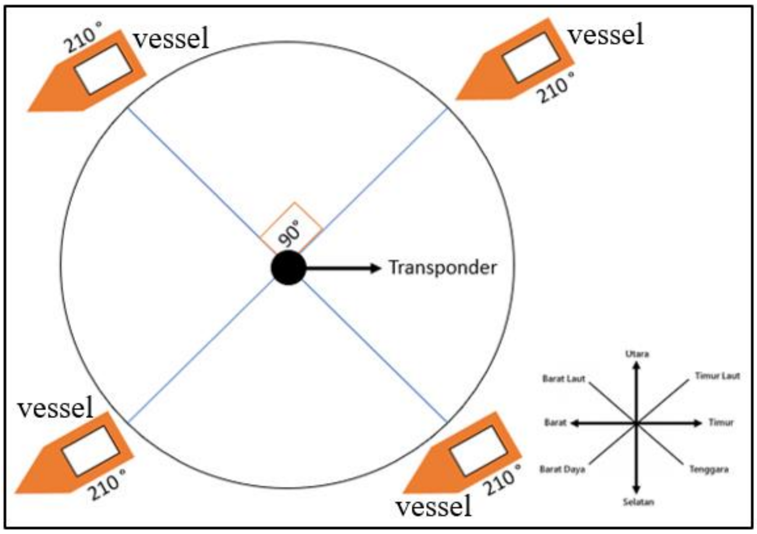


Figure 7. Schematic of Quadrant/Box in Callibration

RESULTS AND DISCUSSION

The transponder position data on a single position static calibration is spread according to fig. 2. From the raw data in table 1, the next process is the calculation as shown in table 2. To get the transponder orientation value, we can use tangential trigonometric equations that convert the Cartesian coordinates (X, Y) into polar coordinates (θ, R), so obtained angle of orientation on the transponder based on Eq. (18). After getting the transponder orientation position, the difference in the transponder orientation can be known. The depth of the transponder is obtained based on the estimated calculation and the transponder depth based on easting and northing position data. The transponder depth based on position coordinates can be calculated through the Pythagorean theorem in the Eq. (19). The Pythagorean theorem is used because the distribution of transponder positions forms a right triangle which can be seen in FIG. 8

$$\mathrm{Tan}\ \theta = \frac{\Delta \mathrm{Easting}}{\Delta \mathrm{Northing}} \tag{18}$$

$$Beacon\ Distance\ Observed = \sqrt{(X1 - X2)^2 + (Y1 - Y2)^2} \tag{19}$$

$$Scale\ Factor = \frac{(Beacon\ Distance\ Obs)}{(Beacon\ Distance\ Cal)} \tag{20}$$

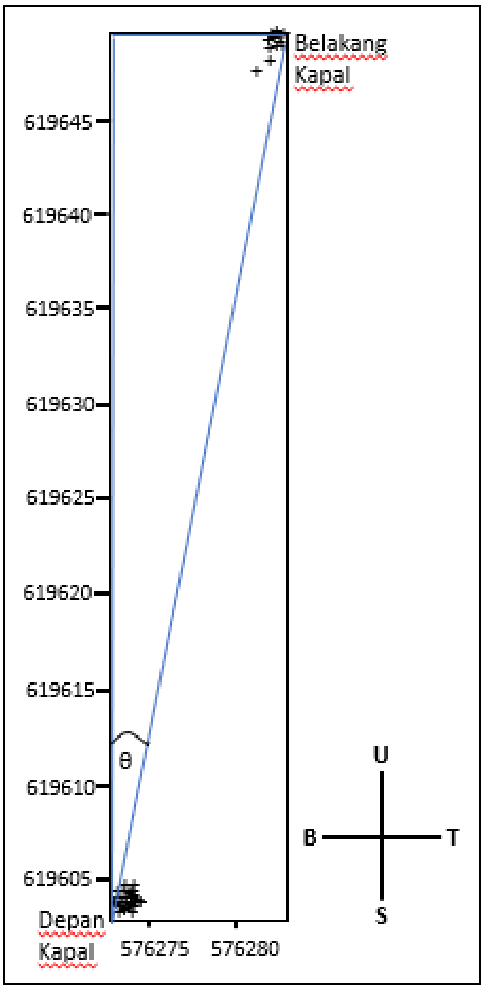


Figure 8. Positioning Distibution Data of Static Callibration

Table 1. Raw Data in Static Callibration

Date	*Time (Loc)*	*Fix No.*	*Stbd_Stern Transponder*		*Stbd Bow Transponder*		*Gyro Orientation (C)*
			Easting (X2)	*Northing (Y_2)*	*Easting (X_1)*	*Northing (Y_1)*	
25/08/2007	16:06:21	2	576281.57	619647.23	576274.8	619603.443	190.7
25/08/2007	16:06:26	3	576282.28	619648.14	576274.86	619603.408	190.8
25/08/2007	16:06:31	4	576282.69	619648.85	576274.79	619603.524	191
25/08/2007	16:06:36	5	576282.88	619649.27	576274.52	619603.703	191.2
25/08/2007	16:06:41	6	576282.98	619649.48	576274.22	619603.721	191.3
25/08/2007	16:06:46	7	576282.77	619649.51	576274.15	619603.654	191.3
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
25/08/2007	16:12:56	81	576282.26	619649.16	576274.40	619604.08	190.80

Table 2. Calculation Data in Static Callibration

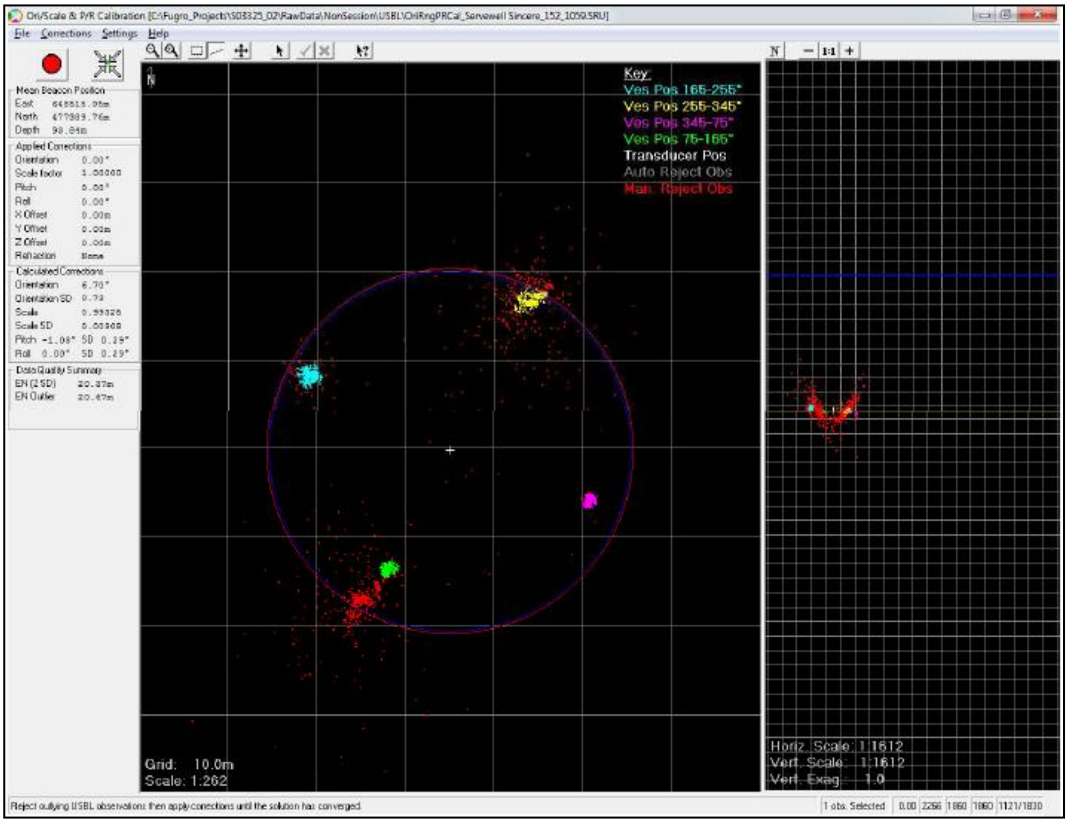
Transponder Orientation (O)	*Orientation C-O*	*Transponder Distance*		*Scale Factor*
		Observed	*Calculated*	
188.83	1.872	44.308	46.400	0.95492

189.47	1.334	45.342	46.400	0.97720
189.93	1.072	46.006	46.400	0.99151
190.43	0.766	46.331	46.400	0.99851
190.89	0.411	46.591	46.400	1.00413
190.69	0.608	46.656	46.400	1.00551
-	-	-	-	-
-	-	-	-	-
189.93	0.866	45.756	46.400	0.98611

Table 3. Correction Result to Orientation and Scale Factor on Static Callibration

Mean Orientation Corr.	1.13°	**Scale Factor**	0.99025
Stand. Deviation	0.461	**Stand. Deviation**	0.012

Keep in mind that the static calibration data only gets orientation and scale factor values. That is because the calibration process is only carried out at that point without changing locations. Based on the average calculation, the mean orientation correction value is 1.13 ° with a standard deviation of 0.461 and a scale factor of 0.99025 with a standard deviation of 0.012



Mean Beacon Position
East 648815.08m
North 477389.76m
Depth 98.84m

Applied Corrections
Orientation 0.00°
Scale factor 1.00000
Pitch 0.00°
Roll 0.00°
X Offset 0.00m
Y Offset 0.00m
Z Offset 0.00m
Refraction None

Calculated Corrections
Orientation 6.70°
Orientation SD 0.72
Scale 0.99328
Scale SD 0.00308
Pitch -1.08° SD 0.29°
Roll 0.00° SD 0.29°

Data Quality Summary
EN (2 SD) 20.37m
EN Outlier 20.47m

Grid: 10.0m
Scale: 1:262

Horiz. Scale: 1:1612
Vert. Scale: 1:1612
Vert. Exag: 1.0

Reject outlying USBL observations then apply corrections until the solution has converged.
1 obs. Selected 0.00 2266 1860 1860 1121/1830

Figure 9. Sebaran Data Posisi Sebelum Kalibrasi

In Fig. 8, locations of transponders which are divided into four spreads located in the northeast, southeast, southwest and northwest. This difference in distribution is due to an error in the effect of ship movement in the form of pitch, roll, and orientation. Therefore, a USBL calibration process is carried out so that errors in the ship's movement effects can be defined and entered into the USBL system. From the quadrant / box in USBL static calibration, the raw data obtained are time, location coordinates, transponder distance to transducer (height), pitch, roll, and orientation. Then the statistical calculation process is carried out to get the error value from the effect of the ship's movement in the form of pitch, roll, orientation and scale factor through the Eq. (21)

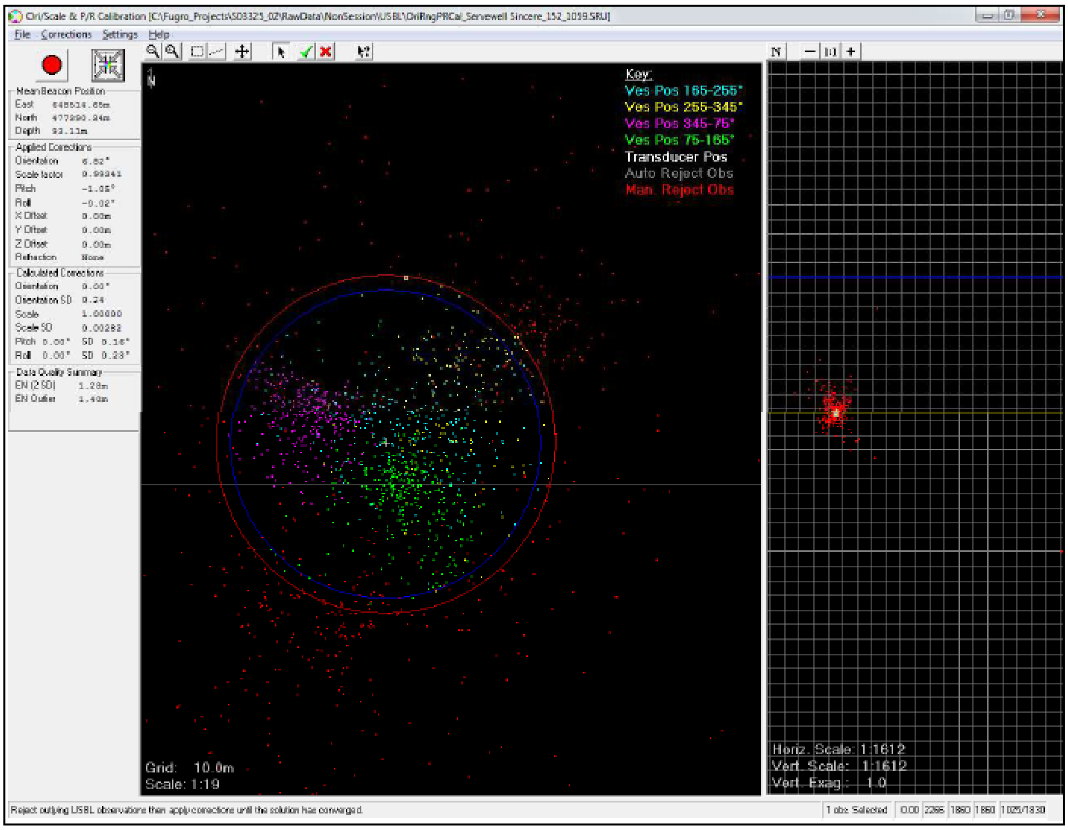
$$Vessel\ Correction = \bar{x} - x \tag{21}$$

Where vessel correction is the correction value of pitch, roll, orientation and scale factor. $\bar{x}$ is the average value and x is the value of each pitch, roll, orientation and scale factor .. After obtaining the vessel correction value, the average and standard deviation of the vessel correction can be identified and used as a parameter of the angular error in the system USBL.

Table 4. Correction Result of Quadrant/Box in Callibration

CORRECTION RESULT	
Orientation	6.82 °
Range Scale	0.9934
Pitch	1.05 °
Roll	0.02 °
X	0 m
Y	0 m
Z	0 m

Table 2 is the result of calculating angular errors in pitch, roll, orientation and scale factor. Fig. 9 is the final data set after the vessel correction is entered into the Starfix NG 2018 software and is re-iterated 9 times. In the picture we can see the spread point locations of transponders that are close to each other compared to before the USBL calibration process is done which means the level of accuracy of the USBL system increases.



Mean Beacon Position
East 648514.65m
North 477290.94m
Depth 93.11m

Applied Corrections
Orientation 6.82°
Scale factor 0.99341
Pitch -1.05°
Roll -0.02°
X Offset 0.00m
Y Offset 0.00m
Z Offset 0.00m
Refraction None

Calculated Corrections
Orientation 0.00°
Orientation SD 0.24
Scale 1.00000
Scale SD 0.00282
Pitch 0.00° SD 0.16°
Roll 0.00° SD 0.23°

Data Quality Summary
EN (2 SD) 1.28m
EN Outlier 1.40m

Grid: 10.0m
Scale: 1:19

Horiz. Scale: 1:1612
Vert. Scale: 1:1612
Vert. Exag.: 1.0

Reject outlying USBL observations then apply corrections until the solution has converged.
1 obs. Selected | 0.00 | 2266 | 1860 | 1860 | 1025/1830

Figure 10. Data Distribution After Callibration

USBL verification is carried out to find out whether the results of the USBL calibration can be used in determining underwater position or not. Verification is done by comparing the position data based on GPS and USBL instruments. The transponder is mounted behind the ship with shallow depth and the absolute position of the transponder is known based on the GPS system. Then, the USBL system also detects the position of the transponder. This difference in GPS and USBL position data is used in the USBL verification process. According to technical procedures, the maximum error value or the difference from USBL verification is 1% of the sea depth. That means, if the position error value of the USBL verification results exceeds 1% of the sea depth of the survey area, the results of the calibration data cannot be accepted and used. In this study, USBL verification was carried out in two different places, namely the Belanak region and the Belida region. In the Belanak Region, it has a sea depth of about 89 m and in the Belida region, it has a sea depth of around 76m

Table 5 Verification Result on Belanak Hasil Verifikasi USBL di Wilayah Belanak

Result	Positioning Error on *Easting* (m)	Positioning Error on *Northing* (m)
Δ Average	0.289	0.276
Standard Deviation	0.364	0.440

Table 6 Verification Result on Belida Field

Hasil	Kesalahan Posisi Pada *Easting* (m)	Kesalahan Posisi Pada *Northing* (m)
Δ Rata-Rata	0.432	- 0.644
Standar Deviasi	0.176	0.156

Based on the results of USBL verification, the position error value on the USBL system is still at an acceptable because it does not exceed 1% of the sea depth. However, the position error in the Belida region was greater than in the Belanak region. In fact, the depth of the Belanak sea is greater than Belida. That is because the sea condition at the time of verification in Belida experienced waves large enough to reduce the accuracy of the USBL.

CONCLUSION

1. Successful calibration of Single Position static USBL (case study off Terengganu, Malaysia) with orientation correction value of 1.13° with a standard deviation of 0.461
2. Quadrant / box in Correction has been successfully calibrated (case study in Keris WHP-K Field) with a pitch correction value of -1.05°, Roll of -0.02°, and Orientation of 6.82°
3. USBL correction has an influence on the accuracy for underwater positioning. This is proven by the scale factor value. For USBL static calibration, it has a scale factor value of 0.99025 with a standard deviation of 0.012. For dynamic USBL calibration, it has a scale factor value of 0.9934.
4. Quadrant / box in calibration results produce a position error of 0.289m in the X coordinate and 0.276m in the Y coordinate at a sea depth of about 89m. In addition, Quadrant / box in calibration also resulted in a position error of 0.432m in the X coordinate and 0.644m in the Y coordinate at a depth of about 76m

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