A Calibration of SSBL Acoustic Positioning System in the Ocean

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***Abstract-* In recent years, precise underwater observations have been performed by autonomous underwater vehicles (AUVs). The super short baseline (SSBL) method is often used to position the vehicle because of its simplicity and efficiency of the operation. Then more accurate positioning by SSBL is requested. The advantages of the SSBL method are the simplicity of the operation and the time efficiency. However, the SSBL is not accurate.**

In this paper, a calibration of the SSBL acoustic positioning system in the ocean is studied. In general, there are random error and systematic error in a measurement system, and the cause of the systematic error is modeled and calibrated for more accurate measurement. In the SSBL method, the error of the attitude of the hydrophone array, which is sensed by a motion sensor, is typically calibrated. Error of the attitude in the hydrophone array, We estimate the calibration that starts in the straight line and the calibration that starts in the circumference and the attitude in the hydrophone array is estimated by the technique for the combination and settling systematic error. And, it was confirmed to be able to estimate the attitude in the hydrophone array by the accuracy of about 0.1 degrees in the verification by the simulation.

I. INTRODUCTION

Global positioning system (GPS), which uses the electromagnetic radiation, is general mean to measure position on the earth. On the other hand, acoustic wave is used to measure underwater position, because the propagation loss of the electromagnetic radiation under the sea is high. The acoustic positioning systems (APSs) are absolute sensing methods based on the GPS positioning of the surface vessel.
There are two popular methods called as long baseline (LBL), and super short baseline (SSBL). The fundamental principles of APSs are similar to GPS.

There is restriction in deployment of the reference points, and in almost case the operation is performed with minimum reference points. There are some ways of the operation and calibration.

LBL method needs to deploy three or more acoustic transponders as reference points. The distance between transponders is several km, and this method is called LBL. The positioning of the LBL method is achieved in the local coordinate frame consists of the reference points. The advantages of the LBL method are the stability and the high accuracy of the measurement. On the other hand, the disadvantages are the complexity and the time-cost of the deployment and the calibration process of the transponders.

The SSBL method may be called as ultra short baseline (USBL), implements the positioning by measuring direction of arrival (DOA) and round-trip time of the acoustic wave from a transponder equipped on the positioning target. The DOA is estimated by a phased array consists of some hydrophones. The distance between hydrophones is several cm and called SSBL. The advantages of the SSBL method are the simplicity of the operation and the time efficiency. However, the SSBL is not accurate comparing with the LBL method.

In recent years, precise underwater observations have been performed by autonomous underwater vehicles (AUVs). The SSBL method is often used to position the vehicle because of its simplicity and efficiency of the operation. Then more accurate positioning by SSBL is requested.

In this paper, a calibration of the SSBL acoustic positioning system in the ocean is studied. In general, there are random error and systematic error in a measurement system, and the cause of the systematic error is modeled and calibrated for more accurate measurement. In the SSBL method, the error of the attitude of the hydrophone array, which is sensed by a motion sensor, is typically calibrated. And, the simulation result by the proposal technique is presented.

II. SSBL POSITIONING

A SSBL method does not use plural propagation time such as a LBL method and uses hydrophone array installed at a wavelength of a sound wave and an interval having a very short it of the degree and measures an DOA for a phase difference of between hydrophones, and it is distance to demand it from hydrophone array and propagation time between hydrophone of one and a method to measure a position I put it together, and to show it in Fig 1.

A basic SSBL acoustic system is constituted by a vessel based hydrophone array and an underwater transponder, as illustrated in Fig 1. In positioning operations, the transducer on the vessel emits an acoustic signal as interrogation to the transponder. Once the transponder receives the signal, it responds to the acoustic interrogation with an acoustic reply. The reply is received by the hydrophone array equipped on bottom of the vessel, yielding bearing φ and depression angle Ψ to the transponder by phase comparison of the arriving acoustic wave between the hydrophones. Based on the time of flight technique, the slant range between the hydrophone array and the transponder is measured. In Fig 1, *Sr* is the slant range. It is calculated in the vessel by the time from transmitting the interrogation to receiving the reply from the transponder on sea bottom.

A SSBL positioning system is intended to measure three dimensional location of the transponder under a local coordinate system, as illustrated in Fig 1. The SSBL positioning system returns values based on the local coordinate system $O_tX_tY_tZ_t$, in which the origin *Ot* is tied to the center of the transducer array, the positive *Yt* axis points straight ahead, and the positive *Xt* axis points towards the right. According to the return values of slant range (*Sr*), bearing (φ), and depression angle (Ψ), the position vector of the transponder in the $O_tX_tY_tZ_t$, coordinate system can be calculated from the following expression:

$$\mathbf{P}_T = \begin{bmatrix} Sr\cos\psi\sin\phi \\ Sr\cos\psi\cos\phi \\ -Sr\sin\psi \end{bmatrix}. \quad (1)$$

III. Calibration Procedure

A SSBL method has a short length of a baseline, and position precision of a *xy* direction is not good.
Therefore influence to a positioning error by an estimate error of DOA grows big in proportion to a ship and distance of a target. A factor and an error of a position error consist of a systematic error and a random error.

For a systematic error factor, things by an installation error of array and a measurement error of an underwater speed of sound profile are thought about. DOA increases the output of motion sensor of array in an incidence angle for array and calculates. An installation error between things of this motion sensor and array has an influence on an estimate of DOA directly. Therefore it is necessary to revise it precisely.

In this paper, an estimation of the target position using the SSBL processed results is calculated as follows,

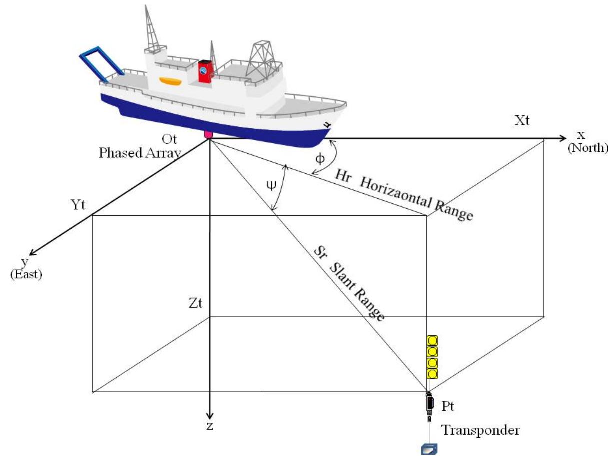


Figure 1. Positioning of SSBL method.

$$\overline{\mathbf{p}}_T^l = \frac{\sum_{l=1}^{N} \frac{\hat{\mathbf{p}}_{T,l}^l}{\tau_{Rx,l}}}{\sum_{l=1}^{N} \frac{1}{\tau_{Rx,l}}}, \quad (2)$$

where, $\overline{\mathbf{p}}_T^l$ is the estimation result, N is number of SSBL processed results, $\hat{\mathbf{p}}_{T,l}^l$ is *l*-th SSBL processed results, and $\tau_{Rx,l}$ is propagation time of acoustic signal of *l*-th SSBL process. The estimation is weighted mean of the results of SSBL calculation of the absolute target position, and $1/\tau_{Rx,l}$ is the weight of *l*-th result.

An error of an attitude

$$\hat{\boldsymbol{\alpha}} = \boldsymbol{\alpha} + \delta\boldsymbol{\alpha} + w_{\boldsymbol{\alpha}} = \begin{pmatrix} \alpha + \delta\alpha + w_\alpha \\ \beta + \delta\beta + w_\beta \\ \gamma + \delta\gamma + w_\gamma \end{pmatrix}, \quad (3a)$$

$$\boldsymbol{\alpha} = \hat{\boldsymbol{\alpha}} - \delta\boldsymbol{\alpha} - w_{\boldsymbol{\alpha}}, \quad (3b)$$

where, α is Roll, β is Pitch and γ is Heading. The random error $w_{\boldsymbol{\alpha}}$ is small by acquire many data. However, a systematic error does not become small. We must estimate a systematic error.

The show dispersion of a position as follows.

$$\mathrm{E}^2 = \frac{1}{N}\sum_{k=1}^{N}\frac{1}{\tau_{Rx,l}}\left(\hat{\mathbf{p}}_{T,k}^l - \overline{\mathbf{p}}_T^l\right)^T\left(\hat{\mathbf{p}}_{T,k}^l - \overline{\mathbf{p}}_T^l\right). \quad (4)$$

This evaluation function is a function of $\boldsymbol{\alpha}$. And, $\overline{\mathbf{p}}_T^l$ is a function of $\boldsymbol{\alpha}$ In other words it is a function of δ .This evaluation function demands $\delta\boldsymbol{\alpha}$ of minimum.

The calculate repeatedly as follows and pursue $\delta\alpha$ and $\delta\alpha_k$.

$$\delta\alpha_{k+1} = \delta\alpha_k - \lambda_{\delta\alpha}\frac{\partial \mathrm{E}^2}{\partial\delta\alpha}, \quad (5)$$

$\delta\alpha$ is a value of a k step. And, λ is an update coefficient.

IV. Simulation Results

In this section, show a result of simulation. Fig 2 shows a horizontal track of vessel in a calibration process in the simulation. The start point of the vessel is (-800m, 0m) and the vessel cruises straightly northward. The track passes over the target transponder.

Figs 3. is the result that gave a systematic error of roll, pitch, and heading separately. Case I is the result of roll, II is of pitch, and III is of heading respectively. As for (a), as for *xy* direction (b), as for *yz* direction (c), *xz* is direction. Figs 4 are the results that revised Figs 3. II (pitch), III (heading) converges. However, a roll does not converge. As for it, a peculiarity be expressed to an error of a roll. And because do not disperse.

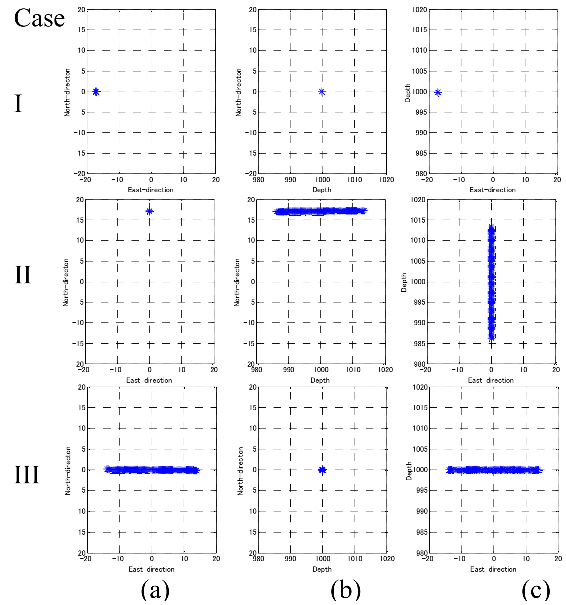
Fig 5 shows a circumference track of vessel in a calibration process in the simulation. The start point does cruise from the north in the circumference of 500m in radius centering on the transponder(0m, 0m). Figs 7. are the results that revised Figs 6.

When did calibration of circumference, I (roll) converges well. However, attention is necessary for revision of pitch and heading. An error to occur by error and Heading occurring by pitch has a similar peculiarity. Therefore a direction of an error is the same, and an estimation function shrinks even if I revise whichever.

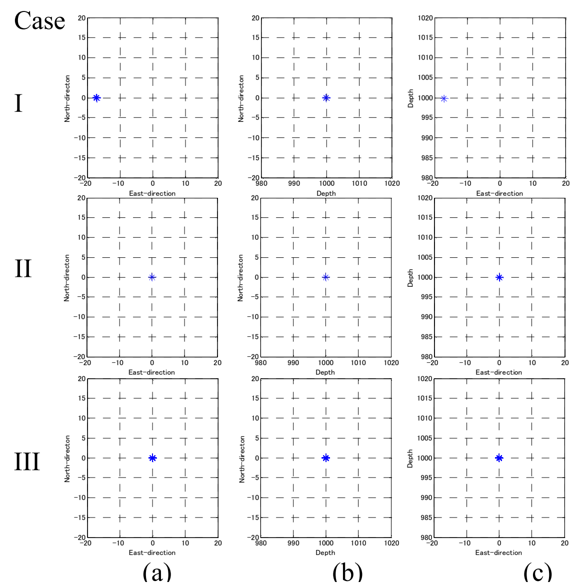
Figure 2. Simulation of a straight track line.

TABLE I. Parameters of the track line.

Course	0
Depth	1000m
Speed	2.0m/s: constant



Figures 3. Plot of the SSBL gave a systematic error



Figures 4. Plot of the SSBL estimation result.

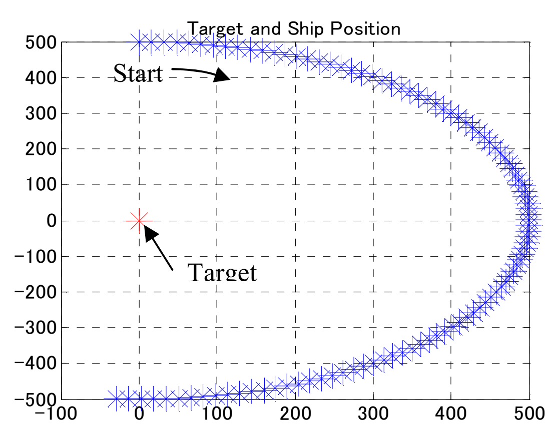
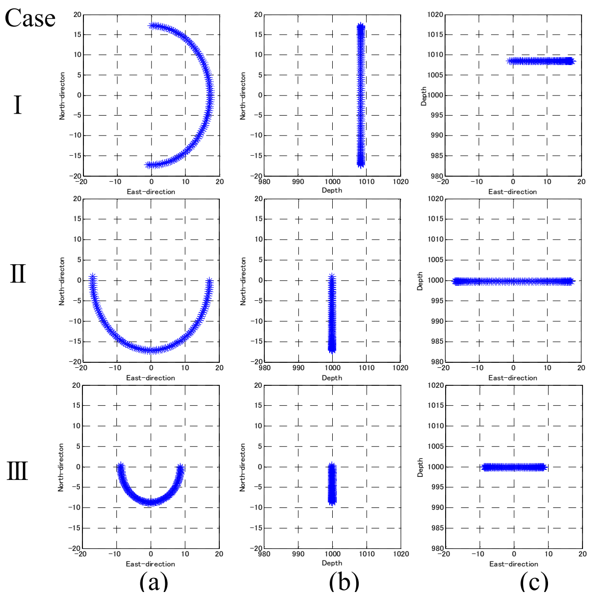


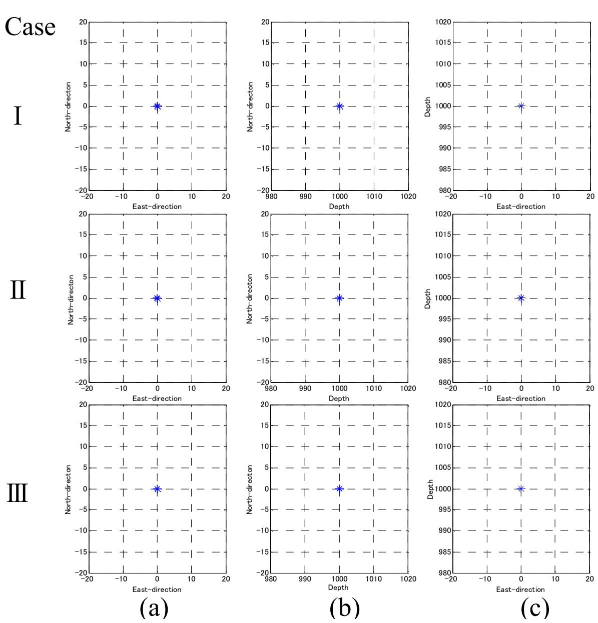
Figure 5. Simulation of a circle track line.

TABLE II. Parameters of the track line.

Center	[0,0]
Radius	500m
Depth	1000m
Speed	2.0m/s: constant



Figures 6. Plot of the SSBL gave a systematic error result.



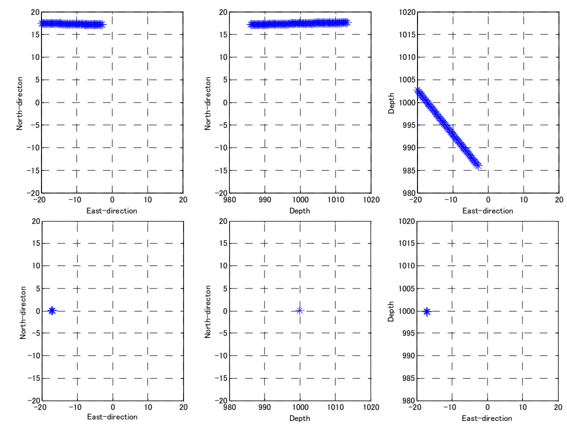
Figures 7. Plot of the SSBL estimation result

Therefore revise an error of pitch and heading by a trail of a straight line by this study and suggest technique to revise a roll error by a trail of a circumference direction.

In a parameter same as Fig 2, simulation was performed.

Figs 8 is the result that gave a systematic error of roll, pitch, and heading simultaneously. And a bottom is the result that revised it.

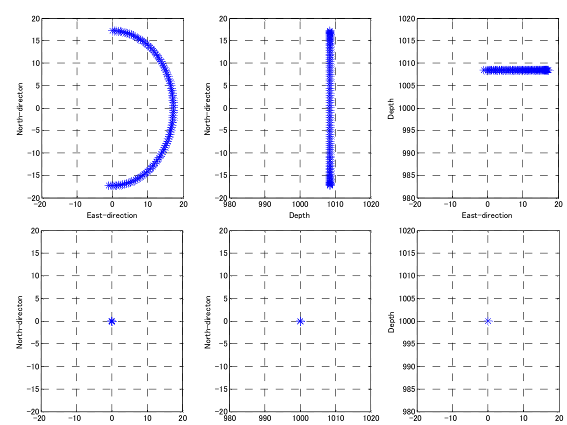
And used the estimation result of the pitch, heading and did revision in a circumference direction same as Fig3. Fig9 is the result. Roll, Pitch and Heading is converges well.



Figures 8. Plot of the SSBL systematic error and estimation result of a straight track line.

TABLE III. Simulated result.

	Systematic error	estimation result
Roll	1	-0.0011
Pitch	1	0.9999
Heading	1	0.9963



Figures 9. Plot of the SSBL systematic error and estimation result of a circle track line.

TABLE IV. Simulated result.

	Systematic error	estimation result
Roll	1	1.0000
Pitch	1-0.9999	-0.0014
Heading	1-0.9963	0.0007

The result of evaluating a random error margin is shown in Fig 10, as follows. It is dispersion of the measurement result and a graph of the estimation error.

If it is about standard deviation=10 of the measurement result, it is possible to settle from the following results by the accuracy of Roll, Pitch, Heading, and 0.1 degrees.

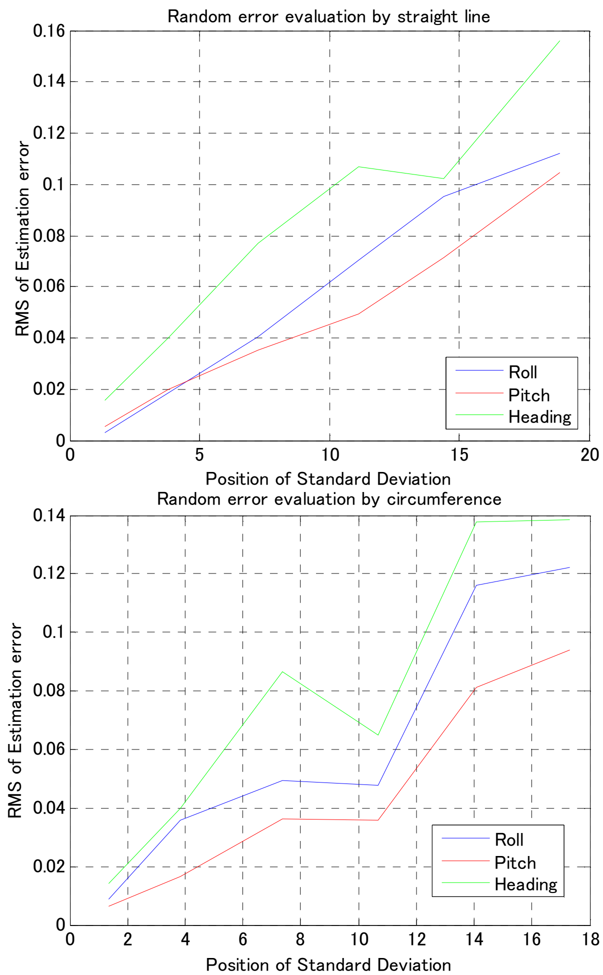


Figure 10a. Simulation of random error result.

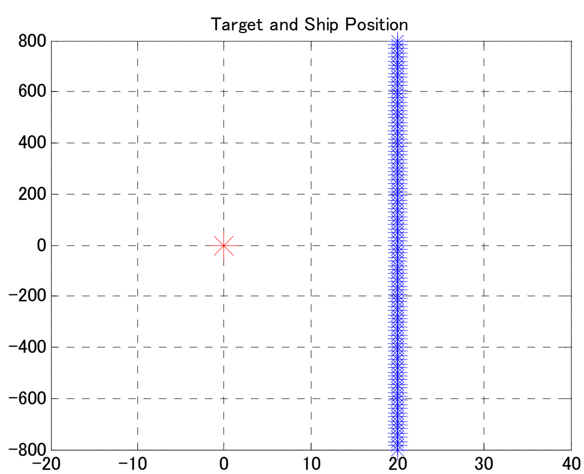


Figure 11. Simulation of a straight track line.

TABLE V Parameters of the track line

Course	0
Line offset	20m
Heading	5 degrees
Depth	1000m
Speed	2.0m/s: constant
Position of SD	12.0756

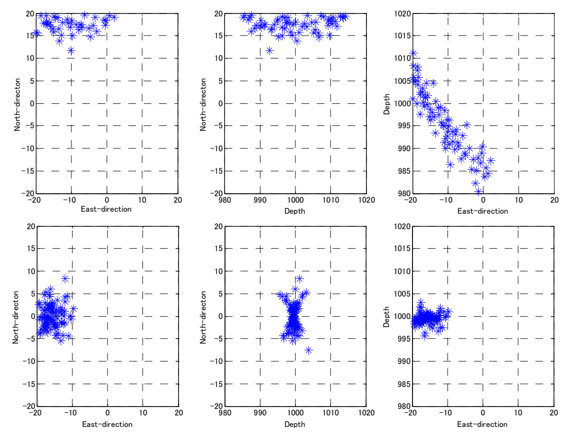

Figures 12. Plot of the SSBL systematic error and random error with estimation result of a straight track line.

TABLE VI Simulated result.

	Systematic error	estimation result
Roll	1	0.0618
Pitch	1	1.0643
Heading	1	0.9608

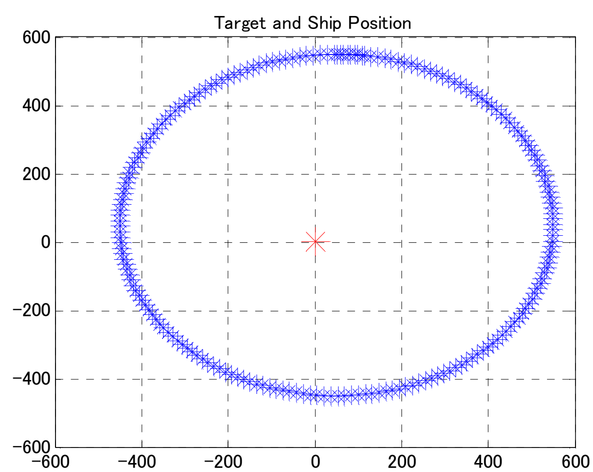


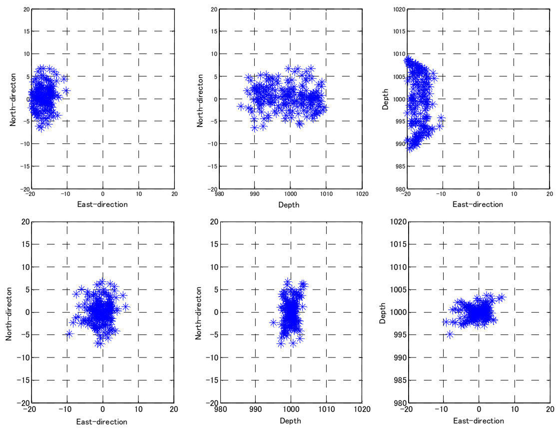
Figure 13. Simulation of a circle track line.

There is a random error by real SSBL operation. When run for a straight line, may not go along right above either. When a course and headers are different, and cannot run for an ideal, a really circle and cannot run straight, there is it.

The simulation result of having given a realistic parameter since Fig10 is shown.

TABLE VII Parameters of the track line

Center	[50,50]
Radius	500m
Heading offset from course line	5 degrees
Depth	1000m
Speed	2.0m/s: constant
Position of SD	7.1289



Figures 14. Plot of the SSBL systematic error and random error with estimation result of a circle track line.

TABLE VIII Simulated result.

	Systematic error	estimation result
Roll	1	0.9679
Pitch	1-1.0643	-0.0697
Heading	1-0.9608	0.0398

V. CONCLUSION

It evaluated it by using the proposal technique in the present study concerning a simulation and a random error margin to estimate the systematic error. As for ideal, if standard deviation at the position is about 10 even if it is a calibration of the condition it is, the calibration of this technique is possible from the above-mentioned result even by a real ocean SSBL operation.

And, it is possible to correct it by about 0.1% in estimation accuracy. And, it is possible to settle by higher accuracy by the repetition calculation.

Further Work

Speed of sound profiles inspect other error factors.

The inspection using ocean experiment data.

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