International Journal of Architectural, Civil and Construction Sciences
ISSN: 2415-1734
Vol:12, No:4, 2018

Image Distortion Correction Method of 2-MHz Side Scan Sonar for Underwater Structure Inspection

Youngseok Kim, Chul Park, Jonghwa Yi, Sangsik Choi

***Abstract*—**The 2-MHz Side Scan SONAR (SSS) attached to the boat for inspection of underwater structures is affected by shaking. It is difficult to determine the exact scale of damage of structure. In this study, a motion sensor is attached to the inside of the 2-MHz SSS to get roll, pitch, and yaw direction data, and developed the image stabilization tool to correct the sonar image. We checked that reliable data can be obtained with an average error rate of 1.99% between the measured value and the actual distance through experiment. It is possible to get the accurate sonar data to inspect damage in underwater structure.

***Keywords*—**Image stabilization, motion sensor, safety inspection, sonar image, underwater structure.

I. Introduction

WITH the deterioration of facilities and the increasing frequency of rainfall due to abnormal weather, the possibility of disasters in bridges and underwater structures is increasing. Recently, the collapsing accidents and danger signs of underwater structures (such as collapse of small bridges and reservoirs, scouring and piping phenomenon) are being issued. In general, conventional methods such as underwater inspection and depth survey by diver have been used to perform underwater inspection. However, as they are largely influenced by flow velocity or turbidity and the limitation on the inspection period is so high that the need for development and application of advanced equipment for underwater inspection has increased. Therefore, SONAR has been emerging [1].

Side Scan SONAR (SSS) is one of the underwater SONAR methods designed to investigate the surface of underwater structure and seabed. In the existing SSS operation method, the SSS and the boat are connected by a cable, and it is impossible to control the SSS at the time of traction, which makes it difficult to scan a desired section. To solve these problems, a dedicated electric jig for SSS has been developed. Since the electric jig with SSS is mounted on the boat, it is possible to overcome the problems in the conventional operation method. However, because the boat and sonar are connected, the image blurring occurs due to a boat rolling caused by wave, the operation of the inexperienced boat driver. Therefore, the sonar image captured by the SSS can be distorted. For this reason, in order to acquire high-quality data when operating the SSS, it is necessary to introduce a motion sensor to detect the shaking that occurs during the operation, and to visualize the filtered image through the image stabilization algorithm. Figs. 1 and 2 show the underwater exploration of the SSS.

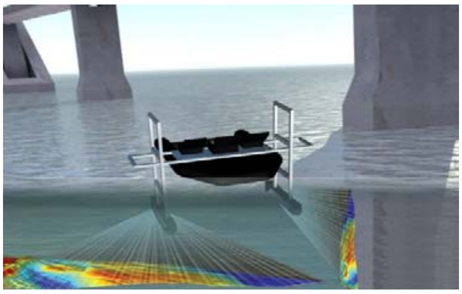


Fig. 1 Underwater Investigation using SS

Fig. 2 Underwater structure survey using SSS

A. Theoretical Background

The sonar (SOund NAvigation and Ranging) is a device that detects the azimuth and distance of a target by a sound wave. Since the electromagnetic wave is transmitted faster and farther than soundwave in the atmosphere, the radar is capable of detecting ground and marine object, and corresponding equipment in underwater is the sonar [3].

The sound wave applied to the Sonar has a pressure wave of about 1,500 m/s and has the property of transmitting well in water [4]. Therefore, so far, various types of sonar have been developed and operated according to the purpose and use, as the only means of detecting targets in the water in an active or passive way.

The SS System is an underwater ultrasonic system that searches both sides. As the vessel towfish (towed underwater) is towed by the traction signal cable, the towfish sends and receives ultrasound underwater from the transducers on both sides. It is a system that transmits a signal through a traction signal cable and restores the shape into a two-dimensional image using a signal and an image processing apparatus [2].

The image stabilization techniques are also applied to digital

Chul Park is with Daum Engineering CO., LTD. Republic of Korea (corresponding author; phone: +82-01-3691-0133; fax: +82-31-776-2996; e-mail: youngseok21c@hanmail.net).

Chul Park, Jonghwa Yi, and Sangisk Choi are with Daum Engineering CO., LTD. Republic of Korea. (e-mail: cseng724@empas., jumsim8@daumeng.com, ssikchoe@hanmail.net).

single lens reflex DSLR (digital single lens reflex) cameras, high-priced lenses and some smart phones. The shaking that occurs during the image shooting leads to a result which is different from the intention of photographer. Each manufacturer's name for image stabilization technology is different (Optical Images Stabilization (OIS), Vibration Reduction (VR), Anti Shake (AS)), but the core principle is the same. This technique measures the tilt when the camera shakes, moves the lens in the direction opposite to the detected shake, or moves the shooting sensor to correct the shake. However, in this paper, we suggest a technique of calculating and correcting the direction and velocity of the shaking motion through the motion sensor considering the characteristics of underwater sonar imaging such as the size of SSS [9].

B. 2MHz Sonar Development and Analysis of Problem

Since the SSS is a device for surveying the seabed form, a wide range was required at a frequency of 400 kHz band. The investigation of the underwater structure can be done precisely if the resolution is higher rather than the photographing width. Along Track Resolution is related to Horizontal Beam Width, operation speed, and Across Track Resolution is determined by Pulse Width and Sampling Frequency. As 1), pulse Width (L) = λ*n, where λ = c/f and n = number of wavelength. The pulse length (L) should be 10 mm or less, since the resolution must be 1 cm or less, that is, 10 mm or less for accurate irradiation. Assuming that the number of wavelengths (n) is 10 ea, and the sound velocity (c in the water is 1,500 m/s on the average, an operating frequency of 1.5 MHz or more is required to have a resolution of 10 mm or less.

$$
\begin{aligned}
&10\,mm > (n \times c)/f \\
&= 10\,mm \times f > (10 \times 1500\ m/s) \\
&= f > (10 \times 1500\ m/s)/10\,mm \\
&= f > 1.5\,MHz
\end{aligned} \quad (1)
$$

Fig. 3 Design of 2-MHz SSS Body

Fig. 4 2-MHz SSS

Since this is the theoretical resolution, the 2 MHz band SSS was developed and applied to the field considering the error in the field. The developed 2-MHz SSS is shown in Figs. 3 and 4.

In the case of a 2-MHz sonar equipment, the resolution is less than 1 cm in the theoretical limit, so it is possible to investigate very precisely. However, the higher the frequency, the higher the resolution and the shorter the range. Therefore, it is needed to be closer scan than 1 MHz sonar. As described above, the image distortion caused by shaking due to close-up photography is increased. In particular, in the case of SSS, sonar images of the surface of underwater structure and seabed are taken while the sonar is mounted on the boat, it is difficult to analyze the data due to the shaking of the image caused by the working environment such as the operation of the inexperienced boat driver. Therefore, it is deemed necessary to develop the image stabilization algorithm and a sonar data post-processing program for effective safety check of underwater structures. Table I shows the resolution and imaging width of sonar equipment according to frequency band.

TABLE I
RESOLUTION AND RANGE ACCORDING TO SONAR FREQUENCY BAND

Frequency	Resolution	Range
400 kHz	5 ~ 7 cm	100 ~ 1,200 m
1 MHz	3 cm	25 ~ 105 m
2 MHz	1 cm	Within 10 m

II. DEVELOPMENT OF IMAGE CORRECTION PROGRAM

A. Image Distortion Causes and Correction Theory

The SSS has a problem that the resolution of collected data varies depending on the angle of the towfish and the distance from the structure. Since most of the cables are operated by towing while connected to boats, there is a phenomenon such as boat rolling caused by waves, the operation of the inexperienced boat driver, and swinging of the sonar body due to collision of an underwater suspension. Because of these working environments, it is often the case that data are difficult to read. To solve these problems, we developed the motion sensor and image stabilization algorithm to detect the shake and correct the image after scan. Table II shows the specifications of the applied motion sensor.

TABLE II
APPLICABLE SENSOR SPECIFICATIONS

	
Azimuth accuracy	<0.5 degrees, 0.1 degrees resolution
Inclination accuracy	Typical 1° accuracy <±30° tilt
Inclination range	±80 degrees
Temperature range	Accuracy specified for 0°C to 50 °C, -40°C to 85°C
Shock (Operating)	3,000 G, 0.5 ms, 10,000 G 0.1ms
Data Refresh Rate	0.01 Hz to 40 Hz sentence output rate

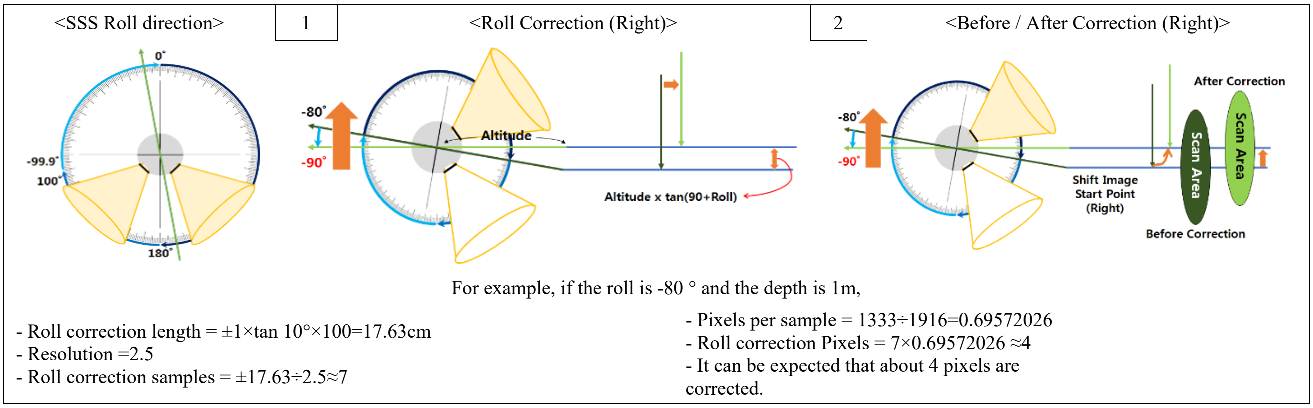
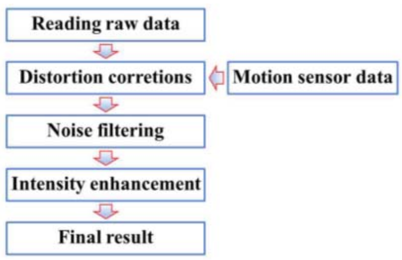


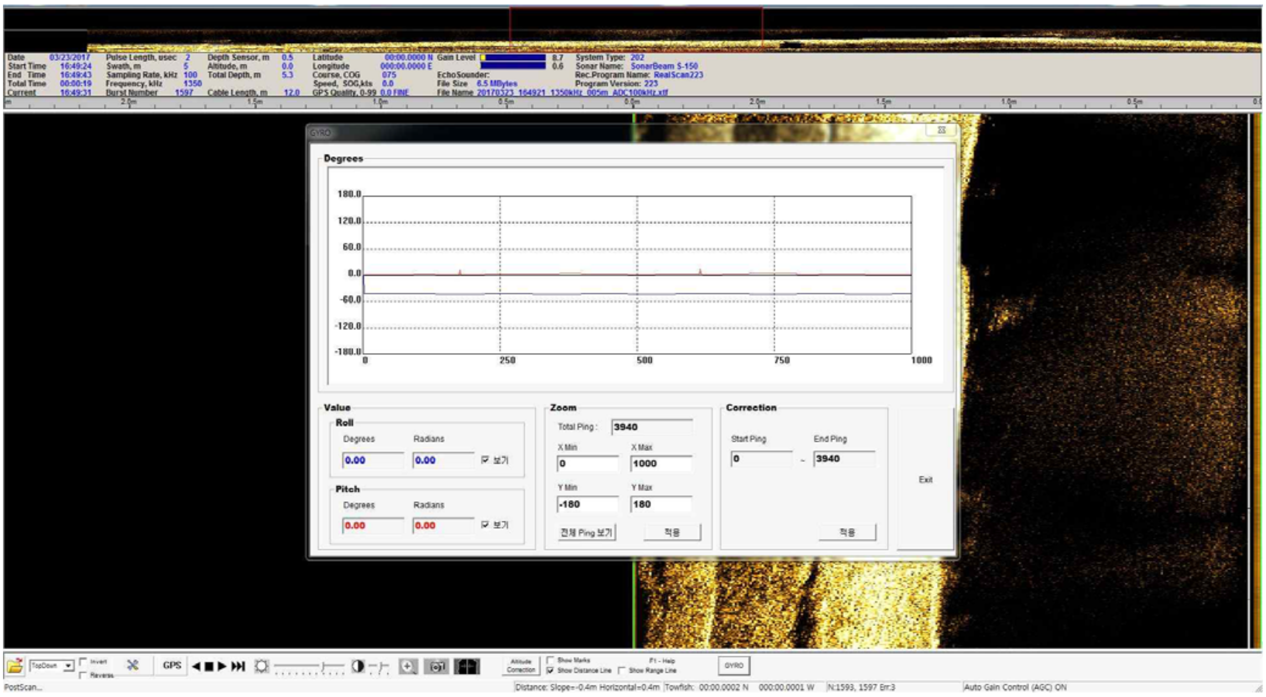
Fig. 5 Image stabilization range and design according to roll range

The image stabilization technique is a combination of techniques for detecting and correcting the shake. The motion sensor is a device that detects and corrects the shaking, and it uses an angular velocity and an acceleration [8].

The angular velocity sensor detects the angular velocity according to the camera shake as an electric signal. The angular velocity sensor detects the rotational angular velocity by using the Coriolis' force generated in the mass body when an angular velocity vector rotation motion is added to a vibrating mass. For detection, it is divided into a roll direction component, a pitch direction component, and a yaw direction component, which are respectively associated with one angular velocity sensor, and three components are synthesized to calculate the shaking direction and velocity. The accelerometer detects the movement of the shaft caused by the vibration and calculates the absolute angle of the swing, thereby correcting the error value of the swing calculated through each speedometer.



(a) Image correction algorithm Flow Chart



(b) PostScan Tool

Fig. 6 Image stabilization tool design [5]

The SSS is bound to the boat and acquires a 2D image in accordance with the direction of the boat. The roll range is '+ 0 ° ~ + 180 °' in the right direction and '-0 ° ~ -99.9 ° and + 100 ° ~ + 180 °' in the left direction. When the roll range is from -80 ° to -99.9 ° and from +100 ° to + 104 ° to the left, the right side is scanned because the lower side is pointing to the right. Fig. 5 shows schematically the range of shake correction and design method according to the roll range [6].

B. The Consist of SS Operating Program

The SSS used in this study consists of two programs: RealScan, which is an operating program, and PostScan, which is a post-processing program. The operating program (RealScan) receives the signal information acquired from the towfish by cable and displays it in real time through the monitor of the Deck Unit. It is a program that receives, processes, outputs and stores sonar signals. The post-processing program (PostScan) is a program that analyzes the acquired data. It contains a number of functions for confirming data information such as GPS correction position confirmation, tilt distance correction, mosaic, and altitude information correction. The image stabilization tool developed a UI to incorporate it into a postscan program. The image stabilization tool through UI design is shown in Fig. 6 [7].

III. Analysis of Field Application

A. Data Comparison

The block joint of the gravity type quaywall structure was scanned using the developed 2-MHz sonar as shown in Fig. 7. As mentioned above, since the boat and the sonar are all acting together, it is seen that the shape of the gravity type block is distorted because of the shaking caused by the rolling phenomenon of the boat by the wave and the operation of inexperienced boat drivers. The roll, pitch and yaw directions obtained from the motion sensor were analyzed, and the data were subjected to image stabilization. As a result, the corrected data were obtained as shown in Fig. 8. It is confirmed that the joint shape of the block is corrected to a straight line shape.

Fig. 7 2-MHz Sonar data before correction

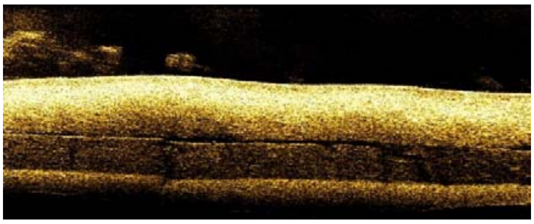


Fig. 8 2-MHz Sonar data after correction

B. Reliability Verification

In this study, the reliability of the 2-MHz SSS with motion sensor and the complimented program for image stabilization were verified by field survey. The sonar images obtained from the field survey are the SSS sonar images without motion sensors (pre-correction images) and the other SSS sonar images with motion sensors (post-correction images). During the image acquisition, the diver was inserted into the deep part of the damage and the actual damage length and depth were measured and analyzed. In the field data collection, underwater irradiation was performed by using the sonar imaging method using electric jig, and 50 samples were extracted and analyzed.

Fig. 6 shows the towfish with the motion sensor and the field survey logarithm. Table III is one of the samples and shows the sonar data corrected by the motion sensor and the damage comparison method.

TABLE III
Comparison of Sonar Data and Damage through Motion Sensor

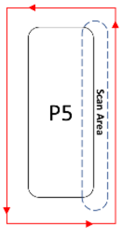
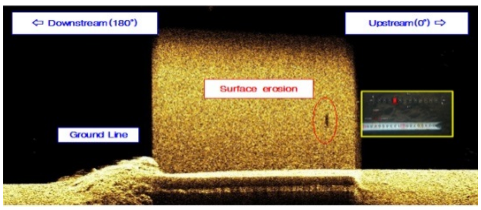
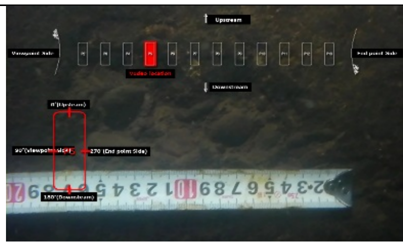
Case	Bridge location	PostScan confirmation video	Diver confirmation video	Error factor
Bridge location				The whole average 1.99%
	Damage occurred P5- 270° (End point side)	Difference length (L=0.21m)	#3. Difference length (L=0.20m)	5%
		Depth of water :3.0m	Depth of water :3.0m	0%

TABLE IV
ANALYSIS OF ERROR RATE BY IMAGE STABILIZATION

Case	Damage location	Before correction (m)	After correction (m)	Actual length (m)	Error rate	
					Before correction	After correction
1	(P3-a 0°)	1.20	1.10	1.10	9.09%	0.00%
2	(P4-a 180°)	2.90	2.70	2.60	11.54%	3.85%
3	(P5-a 0°)	1.60	1.50	1.40	14.29%	7.14%
4	(P6-a 270°)	5.40	4.80	4.70	14.89%	2.13%
5	(P4-b 90°)	0.40	0.50	0.52	23.08%	3.85%
⋮	⋮	⋮	⋮	⋮	⋮	⋮
46	(P10-a 0°)	2.80	2.50	2.45	14.29%	2.04%
47	(P10-c 180°)	0.40	0.40	0.40	0.00%	0.00%
48	(P11-b 90°)	4.10	4.60	4.75	13.68%	3.16%
49	(P13-c 0°)	4.10	4.10	4.00	2.50%	2.50%
50	(P13-c 90°)	0.25	0.21	0.20	23.50%	5.00%
		The whole average			12.43%	1.99%

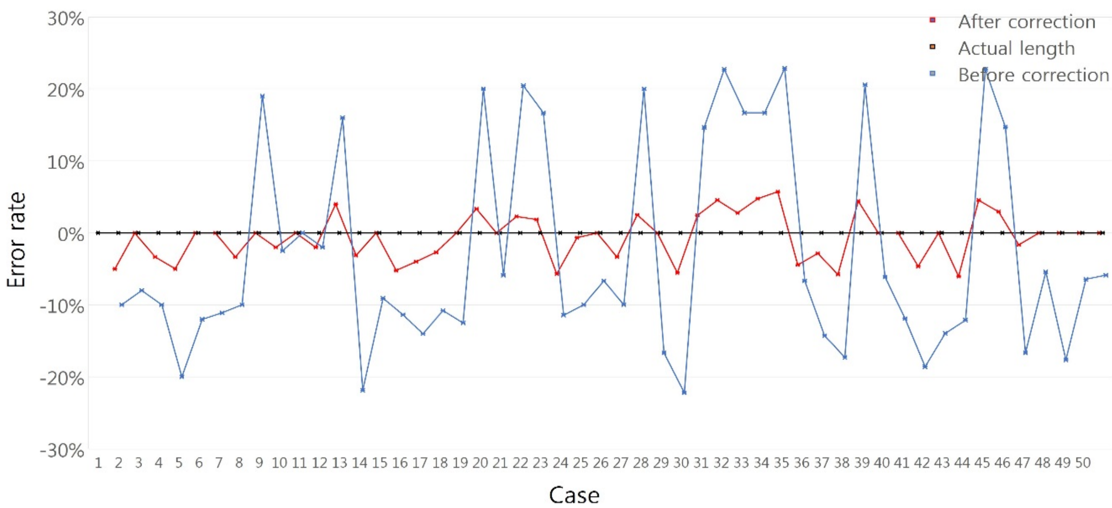


Fig. 9 Error rate comparison between before image stabilization and after image stabilization

The field survey showed the error rate according to the presence or absence of the motion sensor during the SSS sonography. As mentioned above, we compared the pre-corrected sonic image with no motion sensor and the corrected sonic image with motion sensor. We also measured the actual damage length and depth by putting the diver into the suspected damage part. As a result of checking the SSS Sonar images before and after image stabilization, the average error rates were 12.43% and 1.99%, respectively, and the error rate was reduced by 10.43% by using the image stabilization. Table IV shows the field error rate with and without motion sensor. Fig. 9 shows the distribution of error rates for 50 samples before and after correction. The error range before the image stabilization showed 23.79% at -23.50% and the error range after the image stabilization was 7.69% at -7.14%.

IV. CONCLUSION

In this study, we analyzed sonar data resolution enhancement and motion sensor applicability through development of image stabilization algorithm and post scan program tool in order to correct the shaking in 2-MHz SS developed for underwater structure survey.

First of all, we applied the motion sensor inside the 2-MHz SSS to detect and correct the shake caused by the use of SSS. As a result, it is possible to compensate the shaking caused by the working environment, so that reliable data can be obtained with an average error rate of 1.99% between the measured value and the actual distance.

It is considered that convenience and reliability of the user is improved by developing the image stabilization tool in the PostScan.

ACKNOWLEDGMENT

This study is a research project supported by the government (Ministry of Land, Infrastructure, and Transport) the development of unmanned safety diagnosis system for underwater structures through the development of sonar in the high seas (more than 2 MHz class) (17CTAP-C097866-03).

REFERENCES

[1] Kim, Y. S., Lee, H. S., Park, C., Choi, S. S. “A Study for Optimum Survey Method of Underwater Structure Using the Dual Sonar Sensor” Journal of Sensors. Volume 2017, Article ID 9206898, 10 pages, 2017.

[2] Kim, Y. S., Park, C., Choi, S. S. "A Study of Operation Methods for Application of Safety Inspection of Underwater Structures using High Resolution Side Scan Sonar" Korean Society of Coastal Disaster Prevention, Journal of Coastal Disaster Prevention, Vol.3, No. 2, 67-73, 2016.

[3] Moon, I. H., Development of SONAR-based Smart Underwater Inspection System, Sejong University, Seoul, 1-3, 2012.

[4] Park, C. "A Study on the Development of Safety Inspection Method in Underwater Structures Using a High-Resolution SONAR" Hanyang University, Seoul, 126-179, 2015.

[5] Park, J. H., Park, Y. S., Park, C., Lee, J. J. "Development of SONAR-based Smart Underwater Inspection System" Korea Institute for Structural Maintenance and Inspection Conference Vol. 17 No. 2, 126~129, 2013.

[6] Yi, J. H., Park, C., Lee, H. S., Kim, Y. S. "A method development of correctly SONAR image distortion for diagnosis in underwater structure" Korean Society of Civil Engineers, KSCE 2016 Convention Program, 248-249, 2016.

[7] Yi, J. H., Kim, Y. S., Park, C., Choi S. S., Lee, H. S. "A Study of Data Management Methods through Shake Correction of Underwater Investigation Using High Resolution Side Scan SONAR" Journal of the Korea Institute for Structural Maintenance and Inspection, Vol. 21, No. 5, 94-100, 2017.

[8] Ho, Hoai-Nam., Lee, Jong-Jae., Park, Chul., Jo Byung-Wan. "AN Efficient Image Enhancement Algorithm for SONAR Sensor Data" International Journal of Latest Research in Science and Technology, Volume 2, Issue 6: Page No.38-43, 2013.

[9] Ollivier, F., Cervenka, P., and Alais, P. "Side scan SONAR using phased arrays for high resolution imaging and wide swath bathymetry" THE Institution of Electrical Engineers, Vol 143, No.3, pp.163-168, 1996.