Application of Scanning Sonar using Multi - Legged Underwater Robot's Degree of Freedom

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Abstract— Generally scanning sonar can be used with ROV or other equipments. When scanning sonar is operated independently of a ROV, it is most often deployed in a stationary tripod, cage or frame, or pole-mounted to survey the seafloor, port wall, and scour at bottom of the bridge. It could offer high accuracy of image position, in comparison with side scan sonar. However, In high current and shallow water, it was too hard to acquire precise images with these kinds of fixture including gimble so far. When scanning sonar is operated with a universal ROV, it is difficult to survey in strong current water. A scanning sonar attached CR200 can be operated in strong current water because CR200 is designed to overcome this. One of its most advantage is possibility of the variable application with scanning sonar and ultra sound camera because of ability to keep stable posture during the surveying and offer degree of freedom.

We had conducted the performance test of CR200 at Mado, West Sea of Korea where the excavation of the sunken historical objects is in progress last from 16th April to 15th May. To do this we arranged arbitrary targets around the place, searched and collected them.

This paper deals with method of acquiring high quality image from scanning sonar operated with CR200 making full use of degree of freedom and application to navigation with the images in high current and shallow water. CR200 performed successfully the mission to search, identify and collect the imitation relic samples with scanning sonar operation method to figure out to navigation position and to minimize the noise of the conventional sonar image applied to CR200 throughout the experiment.

Keywords—CR200; Crabster; Underwater walking robot; High resolution scanning sonar; Scour; Image mosaic

I. INTRODUCTION

In general sonar systems have two main functions to perform: the detection of objects underwater and the classification of such objects. Moreover, scanning sonar is used on underwater vehicles to aid navigation.

The scanning sonar is able to obtain the image data, such as vertical and horizontal depending on its installation position. In other words, the sonar's attitude must be changed depending on the target to be scanned. The most common way to deploy the scanning sonar for seabed imaging is using a tripod. In order to obtain precise image in curved and sloped seabed, high current and shallow water environment, the followings should be considered.

- Head position and alignment
- Head stability
- Reduces surface reverberation
- Lessens surface multipath
- Decreases slant range distortion

Based on these, for acquisition of precise seafloor image, a narrower vertical beam, tilt transducer, drop-mount instead of tripod, pole-mount, bow-mount or spreader bar have been installing and operating so far[1].

In this article, we would like to present hula-hoop motion coupled with degree of freedom of underwater robot CR200 and operation of scanning sonar rather than mentioned above. Sonar operation with hula-hoop motion enables to obtain precise image data for detection and classification of object and accurate navigation of CR200 in high current and shallow water environment. The appearance of CR200 is shown Fig. 1.

Section II will introduce the specification of scanning sonar used and in section III we'll discuss kinematics about hula-hoop motion that provide pitch angle to direction of sonar head in a raw when it is operated. Section IV and V describe analysis method of precise seafloor image acquired and navigation test results from open sea experiments.

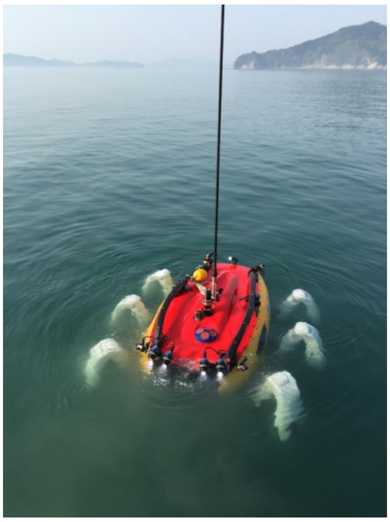

Fig. 1. Appearance of subsea walking robot CR200.

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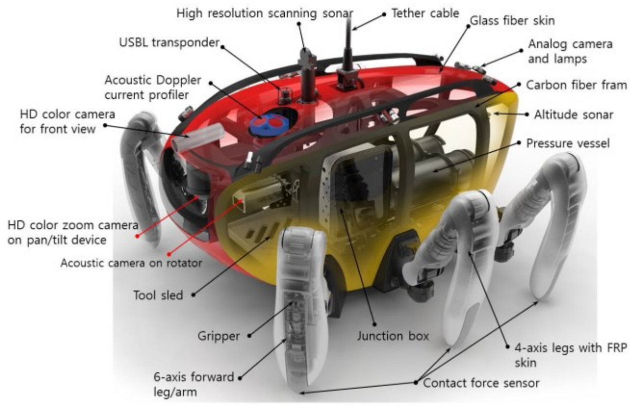

Fig. 2. Equipment configuration of CR200.

II. SCANNING SONAR OF CR200

Fig. 2 shows the appearance of CR200 and equipped exploration devices. CR200 is tethered ROV system and seabed walking robot. The details of CR200 are in [2, 3]. In order to acquire a fine quality of seabed imaging data in a low visibility environment, a high resolution scanning sonar and an acoustic camera are strategically installed at the center-top and front side of the CR200.

A. Specifications

CR200 is equipped with high resolution to detection its surroundings in a low visible. Specification of the 1171 high resolution scanning sonar installed on CR200 is summarized in Table I. The sonar acoustic coverage is shown in Fig. 3[1]. Sonar acquires images while head rotate step size set to a mechanical motor and the range of beam size is 0.9° x 30° as in Table I. During the experiment, the operating parameter of sonar such as the rotate step size, pulse length and rotate rate of sonar head are set each 0.225°, 114 μs and 470s/360°. The direction of rotation of the sonar head can be adjusted in a clockwise or counter-clockwise direction through a sensor operating software and operating frequency is 657 kHz.

B. Reduction technique of surface reverberation

Fig. 4 shows the sonar image obtained from water depth of 5m and 50m operating range with setting above. The sensor head is located 1.6m apart from bottom. The image of the seabed and the water surface seems to overlap because of low water depth and it can be showed as the noise. We can notice that the path of CR200, four anchor lines of support barge and octopus trap are in the seabed reflection signal and in surface reflection signal, hull of barge and surface vessel can be seen. The phenomenon like acoustic multiples, radial pattern and surface return is commonly found when sonar operated in shallow water. The hull of barge is such a strong acoustic reflector, there are returns from the transducer's side lobes. This exacerbates the slant range distortion when the 3D beam is plotted in 2D on the sonar display[1].

The conceptual idea of this paper is to provide "redundant degree of freedom" to rotating sonar head to obtain the image of the seabed or surface continuously. When the horizontal scanning in shallow water, the noise as in Fig. 4 can be minimized to adjust tilt angle of sonar head continuously toward to seabed or water surface.

TABLE I. SPECIFICATIONS OF SCANNING SONAR

Model	**1171 High Resolution Scanning Sonar**
Depth Rating	3,000m
Frequency	675kHz
Beam Width	0.9°×30°~ Fan 1.7°×1.7° Cone
Range	0.5 ~ 100m
Range Resolution	≥ 19mm
Scan Speed	11sec/360° @ 10m & 1.8° step 36sec/360° @ 100m & 1.8° step
Scan Width	360° continuous
Step Size	≥ 0.225°
pulse Lengths	25~2500 μs
Power	33W, 22~60 VDC

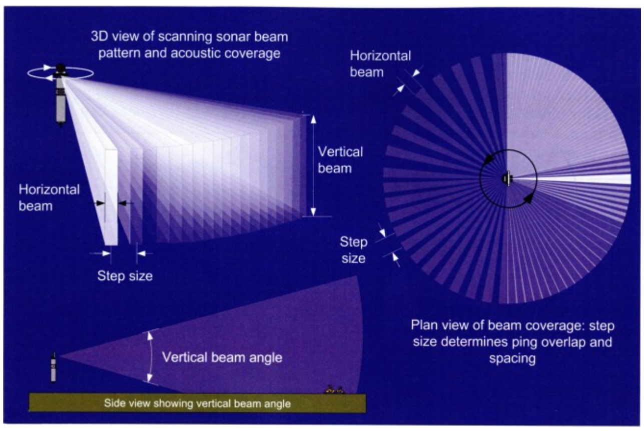

Fig. 3. Scanning sonar acoustic coverage

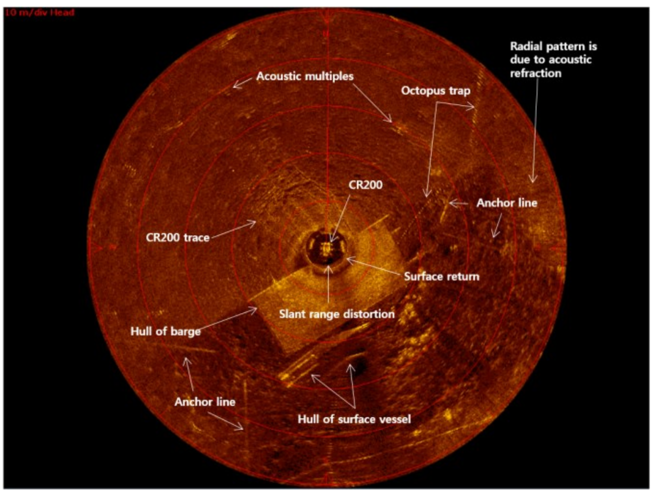

Fig. 4. Result of horizontal scanning

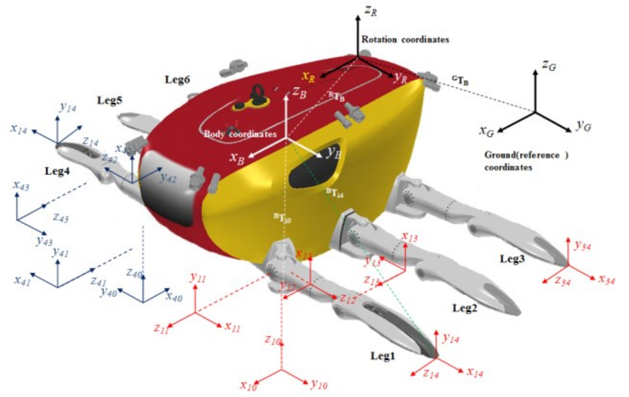

Fig. 5. Coordinate system of CR200

III. KINEMATICS OF CR200

In this section, conical movement(hula-hoop motion) of CR200 to allow the scanning sonar which is using the redundant degree of the freedom selectively to collect image the water surface or the seabed is explained. Conical movement of CR200 can maximize of advantages of ultra-sonic sonar devices in terms of overcoming low visibility and the joint redundancy of CR200 makes the conical motion possible. In order to perform conical movement, the body should be tilted synchronizing the sonar head direction and we need to calculate all of joint angles to make body tilt. We can control the body posture using joint angles which can calculated by relative distance between body reference coordinate and reference coordinate at the end point of each leg. The relative distances between body coordinate and each coordinate at the end-point of the leg calculated by forward kinematics and joint angle values are calculated by inverse kinematics[4]. We use both forward and inverse kinematics to establish the control method of body posture. Fig. 5 shows coordinate system of CR200 and Eq.(1) is derived to calculate each joint angle of the legs to control body posture from coordinate system. Eq.(1) is already derived in [5].

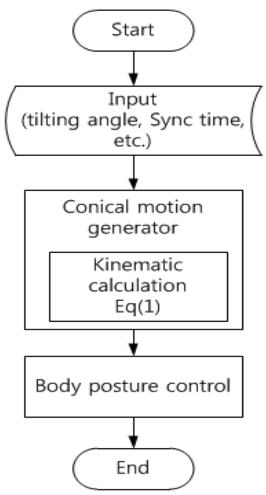

Fig. 6. Flow chart for conical movement of CR200

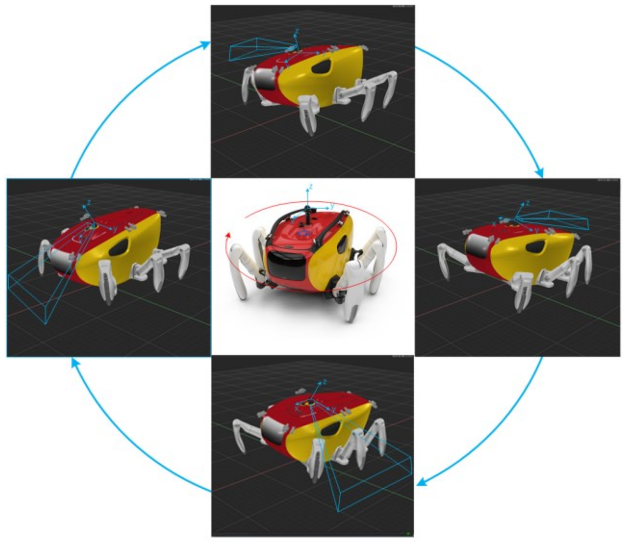

Fig. 7. Simulation results of downward hula-hoop motion[6]

$$ {}^{B}T_{i4} = \left({}^{G}T_{B}^{p}\, {}^{B}T_{R}^{init} R_{ypr} \left({}^{B}T_{R}^{init} \right)^{-1} \right)^{-1} {}^{G}T_{B}^{init}\, {}^{B}T_{i4}^{init} \tag{1} $$

Fig. 6 shows flow chart for conical movement of CR200. When performing hula-hoop motion, tilting angle of the body, synchronizing time duration with the sonar, reference coordinates are required. What you can see in Fig. 7 is simulation result of downward hula-hoop motion adjusting tilt angle continuously to keep sonar heads toward seabed when it rotates clockwise. Upward hula-hoop motion is conical movement same as downward hula-hoop motion however the adjusted tilt angle between upward and downward motion can be differ by 180° so that the sonar can acquire the image of surface.

IV. APPLICATION OF SCANNING SONAR

The analysis method to acquire precise seafloor image data and navigation test results based on this image data using degree of freedom of CR200 from shallow and turbulence water are described in this section. We had conducted open sea experiment from April 16th to May 15th at Mado, west sea of Korea. We named a movement that when sonar head is being rotated, tilt angle is controlled continuously to the sonar head's direction as 'hula-hoop motion' [7]. Hula-hoop motion can be divided in a downward and upward direction along the inclination of the sensor. Downward hula hoop motion is to acquire image continuously scanning sonar facing a seabed and it is useful when using in shallow water. On the other hand, upward hula hoop motion might be serviceable for navigation by continuously acquiring image from offshore structure facing sea surface.

A. Reduction technique

As explained above, there are two movements mainly used in this experiment; upward hula-hoop and downward hula-hoop motion. Fig. 10 shows the results image with attitude by 8°

TABLE II. THE SURFACE REVERBERATION AREA

Motion	Upward	Horizontal	Downward
Range of first surface reverberation	11.46m	16.42m	27.78m
Surface reverberation area	7437.62m^2	7003.41m^2	5426.78m^2
Area %	106.1%	100%	77.48%

upward hula-hoop motion, horizontal scanning and 8° downward hula-hoop motion respectively. 3D beam width and inclination of the sonar are at the top of the picture and middle part of the picture, the areas where the sonar is exposed to the surface are represented. The bottom images in circle show sonar image acquired open sea site. Sonar image acquired from water depth of 6m by 8° downward hula-hoop motion is showed right most side of the Fig. 10. The upper side of images show 3D region of sonar beam that can be covered by rotating the vertical beam size of 30°. The green line is height of sonar head and it is 1.6m apart from seabed. The red line means sonar head is 8° tilted down from horizon. The blue area in the picture is surface reverberation and the smaller the area the less water reflection noise occurs. ‘Area %’ in Table II means difference between 8° downward and 8° upward hula-hoop surface reverberation when the surface reverberation area was assumed to be 100% at horizontally operating. When sonar operated downward hula-hoop motion the surface reflective area has decreased by 22.5% compared to the horizontal attitude. Consequently radial pattern noise generated at surface is reduced and seabed image is appeared more. Besides, the sharp edge of the barge shown in a clear line when operated 8° downward hula-hoop motion while

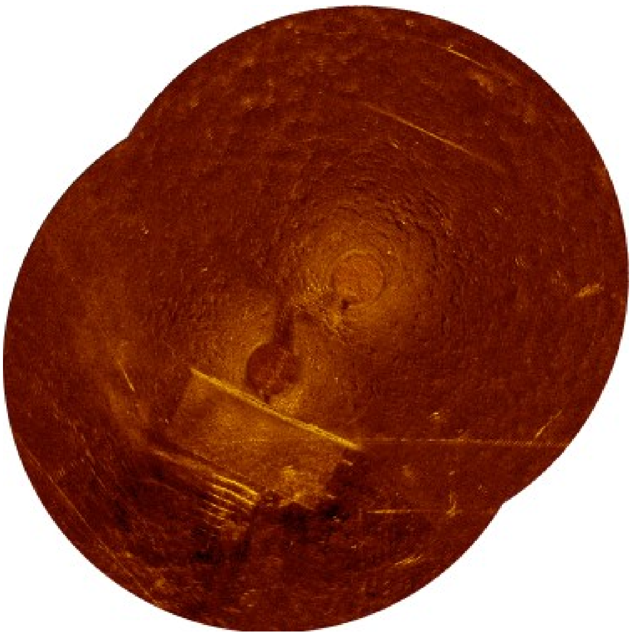

Fig. 8. Mosaic of two sonar images

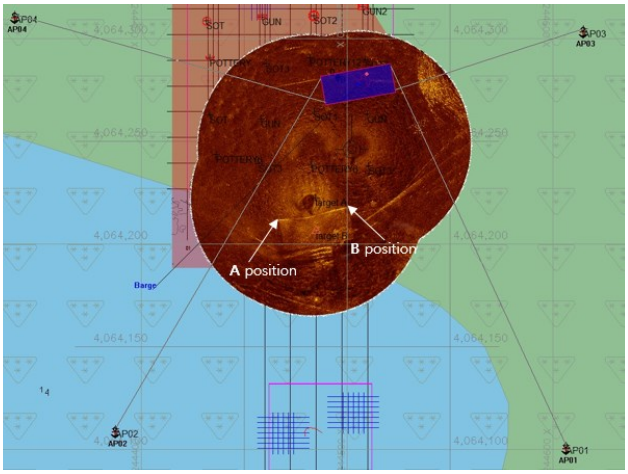

Fig. 9. Application on navigation

two lines were showed in horizontal and 8° upward hula-hoop motion due to multipath.

The navigation efficiency could be improved by downward hula-hoop motion operation of sonar which enables to acquire wider and more precise images by just one scanning. Therefore, data utilization is high for mosaicking. Fig. 8 shows results of mosaicking two acquired images by downward hula-hoop motion.

The left most side image of the Fig. 10 shows result of upward hula-hoop motion and it has more 6.1% of surface reflection area compared to horizontal scanning. On the image you can see buoys at regular intervals attached cable between barge and CR200, surface return and fish school. The image obtained by upward hula-hoop motion which is able to acquire surface and hull of barge image can be utilized in the navigation data for CR200.

B. *Use of the navigation*

In most cases, scanning sonar installed on ROV is utilized in navigation. However, in circumstance with high current where generates vibration, it is not easy to arbitrarily adjust the height of the sensor. In addition to this, it is impossible sensor to maintain constant inclination. CR200 is possible to control to the desired height, direction by using a degree of freedom[8]. In this experiment, we got the hull of barge image data first to take advantage of scanning sonar image to navigation. The DGPS had installed to support barge so that we can recognize edge of barge marked ‘A position’ and ‘B position’ in Fig. 9. After moving CR200, the acquired seabed image and barge image on surface can be overlapped and merged with electrical navigation chart by mosaicking and we can use this as a precision seafloor navigation data.

V. CONCLUSION

This paper dealt with the utilization method for scanning sonar using the freedom of degree of CR200. Two application cases(upward and downward hula-hoop motion) which are coupled with rotation of the scanning sonar and motion of CR200 are introduced. The sonar image acquired by operating downward hula-hoop motion can minimize surface noise so that enable to obtain a precise and wider images compared to use tripod or fixed jig at horizontal scanning. And the other one, images obtained by operating upward hula-hoop motion can show hull of support barge and case using navigation data which utilize DGPS coordinates and barge position on sonar image were introduced. Consequently synchronizing the scanning sonar and the degree of the freedom of CR200 brought increasing efficiency and precision of exploration in shallow water. In near future, we'll analyze the workspace of CR200 and plan to calculate the maximum hula-hoop motion angles to utilize in open sea trial experiment.

REFERENCES

[1] Mark W. Atherton, "Echoes and Images - The Encyclopedia of Side-Scan and Scanning Sonar Operations," Published by OysterInk Publications, Vancouver, BC. Canada, 2011

[2] B.H. Jun, H. Shim, B. Kim, J.Y. Park, H. Baek, P.M. Lee, W.J.Kim, Y.S. Park, "Preliminary Design of the Multi-Legged Underwater Walking CR200", Proc. of the IEEE/OES Oceans 2012, Yeosu, Korea, 2012.

[3] B. H. Jun, H. Shim, J. Y. Park, B. Kim, P. M. Lee, "A New Concept and Technologies of Multi-Legged Underwater Robot for High Tidal Current," Proc. of Underwater Technology, 2011 IEEE Symposium on and 2011 Workshop on Scientific Use of Submarine Cables and Related Technologies, April 2011

[4] Yoo, S., Jun, B., and Shim, H., "Design of Static Gait Algorithm for Hexapod Subsea Walking Robot: Crabster, " Trans. on Korean Soc.of Mech. Eng. A, Vol.38, No.9, pp. 989-997, 2014

[5] S. Yoo, H. Shim, B. Jun, G. Lee, H. Kang and P. Lee, "Underwater Positioning of Multi-legged Subsea Robot for Submarine Exploration Equipment," Proceedings of 18th Int'l Symp. On Unmanned Untethered Submersible Technology(UUST), pp.1~5, 2013.

[6] Yoo, S., Jun, B., Shim, H., Park, J., Baek, H., Kim, B., Lee, G., Kang, H., Jeong, W., Baek, S., and Lee, P., "Preliminary Water Tank Test of a Multi-legged Underwater Robot for Seabed Explorations," to be presented at MTS/IEEE Oceans'15, Washington DC, 2015.

[7] H. Baek, B.h. Jun, J.Y. Park, B.R. Kim, P.M. Lee, "Application of High Resolution Scanning Sonar with Multi-Legged Underwater Robot", Proc. of the Oceans'13 MTS/IEEE San Diego, 2013

[8] J.Y. Park, G.M. Lee, H.W. Shim, H. Baek, P.M. Lee, B.H. Jun, "Head Alignment of a Single-beam Scanning SONAR installed on a Multi-legged Underwater Robot," Proceedings of MTS/IEEE OCEANS 2012 Hampton road, Virginia, 2012

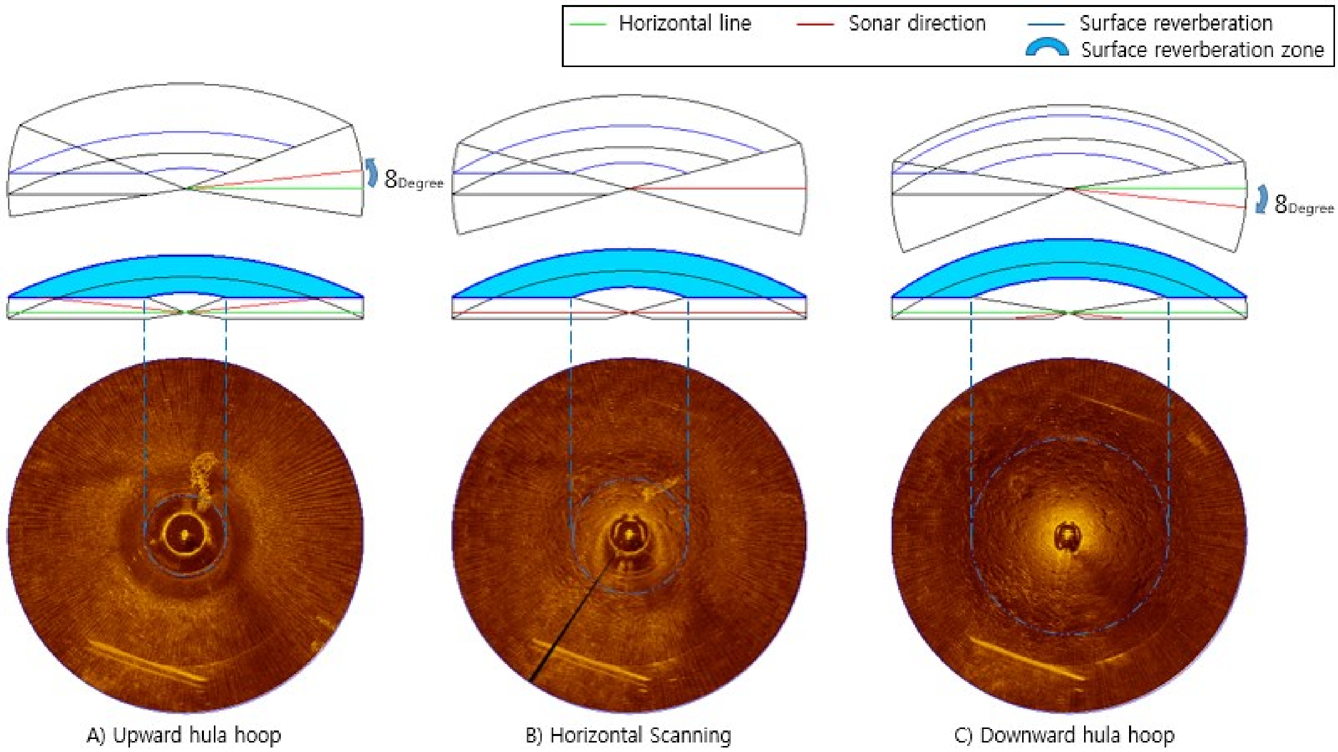

Fig. 10. Comparison of scanning images and diagrams of surface reverberation zone according to each hula-hoop motion