Application of High Resolution Scanning Sonar with Multi - Legged Underwater Robot

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Abstract— This study looks into the high resolution scanning sonar application with multi legged underwater robot. Generally these sonars acquire horizontal images by using a tripod. But in shallow water, it is tough to get detailed images because of surface reverberation and multipath. To solve these problems, we had conventionally installed some motors to offer pitch angle to sensor itself, reduced size of vertical beam and operating ranges. However, these methods also cannot be the ultimate solution. The tripod still existed and the posture provided by it was always unstable. So, we obtained image data using high resolution scanning sonar and reviewed application probability of it with CR200, which can supply desired posture and inclination.

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

I. INTRODUCTION

Typical underwater robots or vehicles have propellers to thrust themselves. Propellers have shown high propulsion efficiency and have been established well. However, there are two major defects for propellers. First, in high tidal environment, it is difficult for underwater vehicles to have precise survey or manipulating works to keep their positions. The other is that the propeller flow disturbs sediment in the floor and makes the water turbid and opaque. To overcome these defects and to perform precise manipulating or sampling, we have developed a multi-legged underwater robot named CR200 since 2010 [1].

The underwater walking robot CR200 was built based on the concept of Crabster. The main mission of CR200 is to thoroughly conduct inspection of shipwrecks or scour and survey of seafloor tomography in high current and turbid environment. The CR200 controls attitude and gets mobility from the six legs instead of screws[2]. The appearance of CR200 is shown in Fig. 1. CR200 is equipped with two kinds of acoustic sensors to survey its surroundings in a low visible and strong turbid underwater floor. One is a multi-beam acoustic camera. This acoustic camera shows us high resolution images, but restricted to short range and narrow band. The other is high resolution scanning sonar. This sonar acquires circular images having relative longer range than the acoustic camera. Geological conditions of the target area affects interpretations of the sonar images[3]. Hence, it is required to measure and control the attitude of the sonar. The scanning sonar operation concept of CR200 is illustrated in figure 2. CR200 is available pitch angle control , altitude control of sensor center, heading and motion control.

We've conducted open sea trials to review the application probability of high resolution scanning sonar when it works with CR200. In order to clarify a comparison of the results, we carried out the tests in two cases when the sensor was installed with a tripod and CR200. Each case is described in section Ⅱ and Ⅲ. In section Ⅳ, we brought out a posture control of CR200 to run it in shallow depth. The accomplishments and future plan for this study are discussed in section Ⅴ.

Fig. 1. Appearance of subsea walking robot CR200.

Fig. 2. Scanning concept of CR200

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II. OPERATING WITH TRIPOD

A. Specifications

Specification of the 1171 high resolution scanning sonar installed on CR200 is summarized in Table 1. The sonar acoustic coverage is shown in Fig. 3[3]. Sonar acquires images while head rotate step size set to a mechanical motor and the range of beam size is 0.9° x 30° like shown in Table 1.

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	

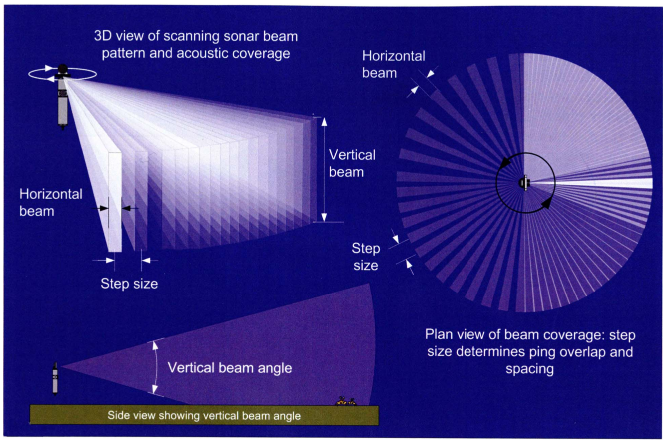


Fig. 3. Scanning sonar acoustic coverage

B. Subsea Tests and Mosaic Result

The experiment was carried out from April 3 to April 6, 2012 at the Pier of South Sea Research Institute to get horizontal images using the 1171 high resolution scanning sonar. We acquired the 15 horizontal images near the pier of South Sea Research Institute by operating the high resolution scanning sonar with a tripod as depicted in Fig. 3. We have stitched the images using Adobe Photoshop CS 6® [4]. As a result of stitched images shown in Fig. 5, we could show seabed of the site as 6,417(width pixel) x 4,861(height pixel) and its actual area 284m x 258m.

Fig. 4. Tripod with 1171 high resolution scanning sonar

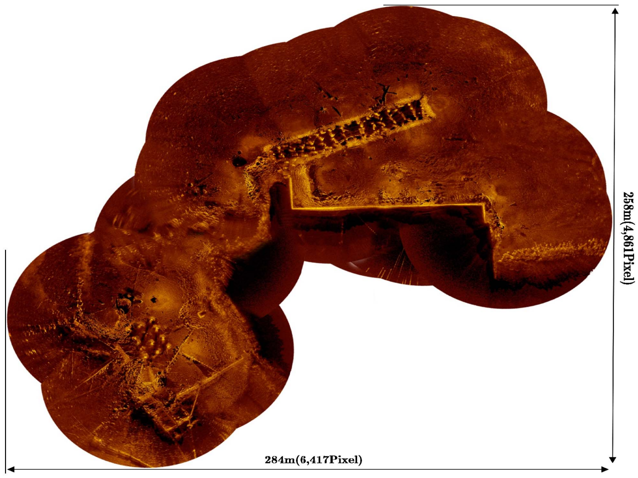


Fig. 5. Result of the sonar image mosaic

C. Result Analys of Horizontal Image with Tripod

The left side of Fig. 6 presents sonar image of seabed when head step size 0.225° and 50 meter range and the photographs are float structures shown in sonar image. The depth was approximately 6~7 meter; thus, surface noise of the water and floating structure images are overlapped after 15~20 meter from center of the sonar image. Consequently, in shallow water the size of surface reverberation gets bigger because the distance of the surface and sensor is close and getting detailed images is quite difficult due to floating structures, which included the site, surface noise caused by waves, and a boat screw as well as the multipath.

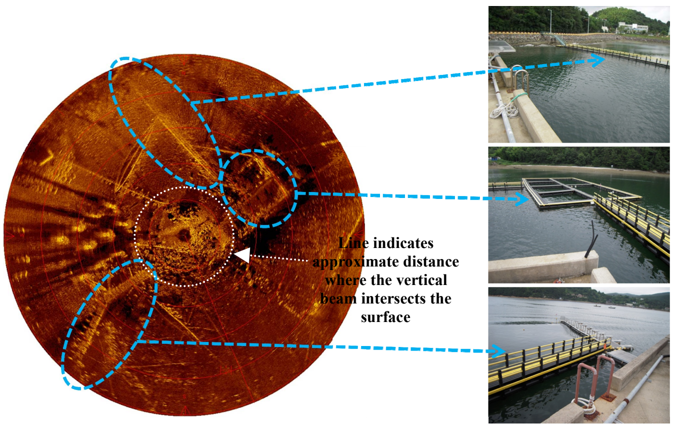


Fig. 6. The vertical beam intersects the surface

D. Surface Reverberation

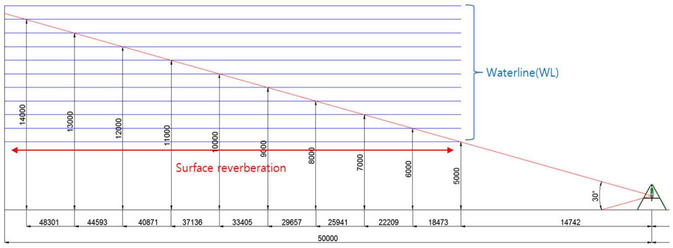


Fig. 7. Surface reverberation length relationships between depth and range

Since size of vertical angle is fixed at 30°, relationships between depth and operating range can be presented as illustrated in Fig. 7. When image is being acquired using a tripod with 50 meter range, surface reverberation cannot be seen over 15 meter depth, but there is still surface reverberation noticed with the range between 18.4 and 50 meter at 6 meter depth. In order to minimize area of the surface reverberation, sonar's operating range had to be reduced or vertical beam angle had to be narrowed and tilted, but they could not offer precise posture and could not incline to the sensor because of tripod.

III. OPERATING WITH CR200

In this section, the image acquiring test results that was carried out on July 9, 2013 at the Pier of South Sea Research Institute are reviewed. The operating condition of the sensor was 50 meter range at 6.5 meter depth and the vertical beam was not exposed outside of water by controlling CR200's attitude. The scanning sonar is attached to the CR200, which is able to move to a pitch direction by an operator; thus, the sensor could have desired pitch angle either shown in Fig. 8.

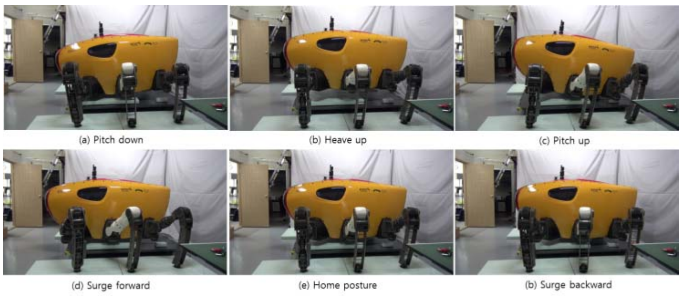
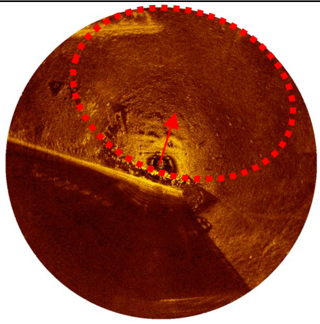
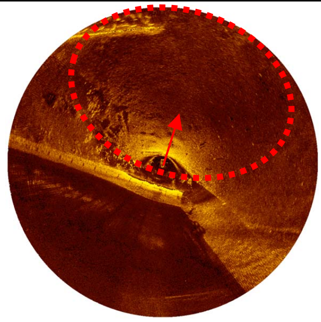
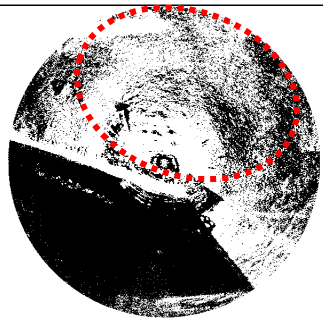
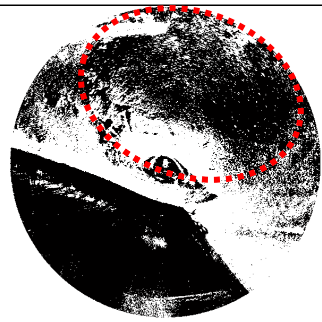
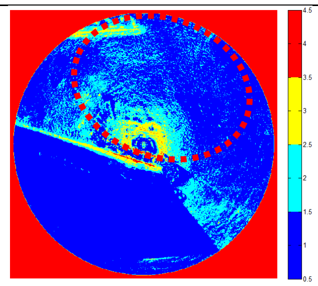
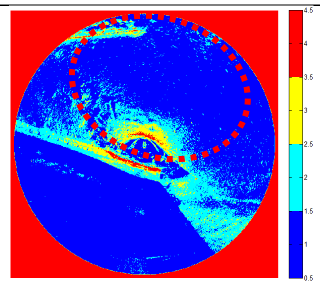


Fig. 8. Posture control of CR200 in XZ-plane

A. Horizontal Image Analysis

Table 2 displays acquired images that CR200 assumed a posture of pitch -16° to heading direction when it stood up at the bottom. In the picture, the arrow means direction of heading and the dotted circle signifies interested area to compare the change of images from CR200 heading. Consequentially, as the area of surface reverberation was reduced to heading direction, the influence of the surface noise was minimized. In contrast, the opposite happened to the anti-heading direction. In order to compare the images effectively, grayscale with 2 stages was inserted like as second row using 4 stages color-scale; strong signal points and low signal points could be separated with red and blue line. In comparison with the left side image, blue color points disappeared and red color points spread out on the right one. Especially, in the third row, the appearing structure from 10 to 12 o'clock direction is indicated in red with controlling pitch, which was yellow before not adjusting the attitude control.

TABLE II. IMAGES FROM DIFFERENT PITCH

Pitch 0°	Pitch -16°
	
	
	

B. Controlling of Inclination Angle

In shallow water within 15meter, the desired pitch angle to get detailed images with CR200 could be calculated by equation (1). Where α is the maximum angle indicated not arising surface reverberation upward on a surface, D is depth from CTD, and L is operating range set to scanning sonar. As Fig. 9 shows above, the vertical beam of sensor is 30° and the angle that 15° subtracted from α is pitch angle of the sensor. Finally the inclination angle of CR200 can be found with equation (1).

$$\alpha = tan^{-1}\frac{D}{L} \tag{1}$$

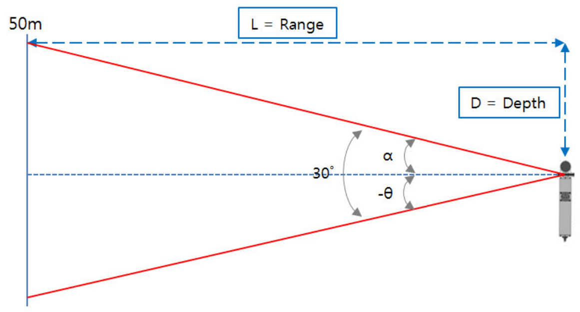


Fig. 9. Pitch inclination calculation of the scanning sonar

C. Illustration of Inclination Angle on CR200

In order to verify the result of calculated water depth, the desired inclination angle of CR200 is plotted when it operates 50 meter range at 5 meter to 15 meter depth on AutoCAD. The indicated angles at the left bottom is α in the equation (1) and their values in a minimum of 5.71° to 16.7°. CR200 can acquire precise images by assuming a posture of -9.29° to 1.7° on X-Z plane because 15° - α means inclination angle of CR200.

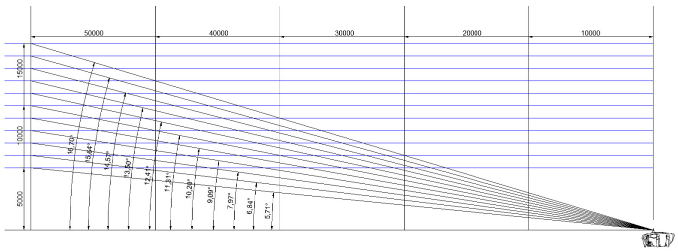


Fig. 10. Illustration of inclination angle on CR200

IV. KINEMATIC MODEL OF CR200

A. Kinematic Model and D-H Parameters

In this session, a simplified kinematic model of CR200 is introduced. Fig. 9 exhibits the coordinate systems for CR200. The ground coordinate and the body coordinate are denoted. Lengths of legs and body are depicted in Fig. 10. On the other hand, Fig. 11 shows links and joints of Leg 2; Table 3 denotes D-H parameters in the case of Leg 2 defined by [5]. Considering symmetric kinematic configuration of the robot, we investigated the kinematic model and motion with respect to the frontal plane (yB-zB plane) only. Therefore, Joint 0 and 2 can be neglected [6].

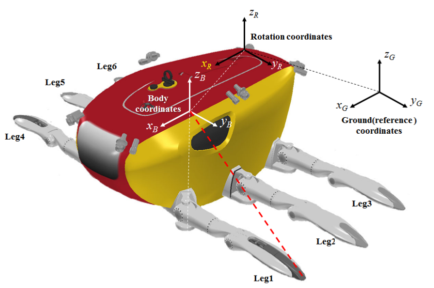


Fig. 11. Coordinate system of CR200 and installation of the scanning sonar

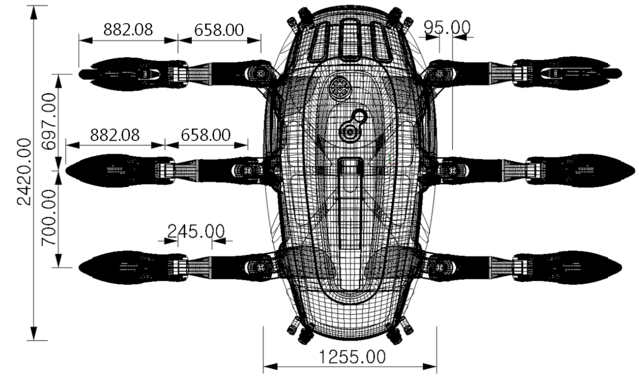


Fig. 12. Kinematic parameters of CR200

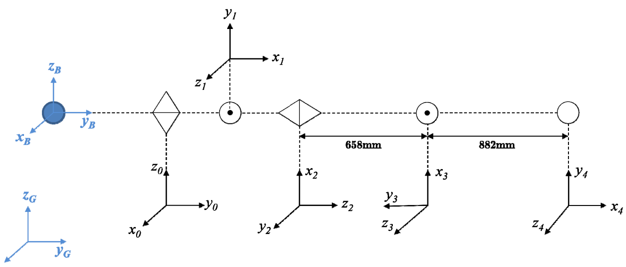


Fig. 13. D-H Parameters of 2nd leg of CR200

TABLE III. D-H PARAMETERS IN THE CASE OF LEG 2

	θ_i	α_i	a_i	d_i
1	90°	90°	0	0
2	90°	90°	0	0
3	0	-90°	0	0.658
4	-90	0	0.882	0

B. Body Contouring for Simulation

A simplified model of CR200 simulated on Matlab is shown in Fig. 14. The decahedron of the middle is a body connected by 6 legs on the plane and the body coordinate system is presented in the middle of it.

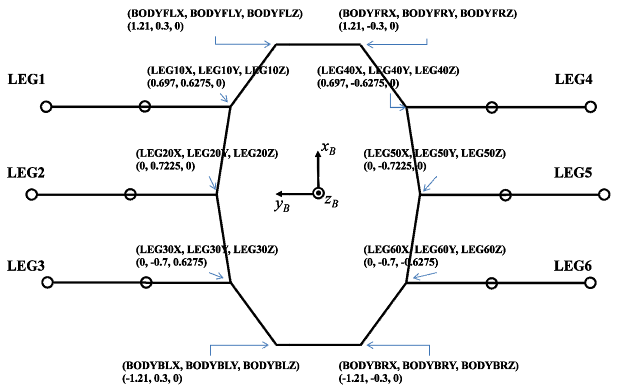
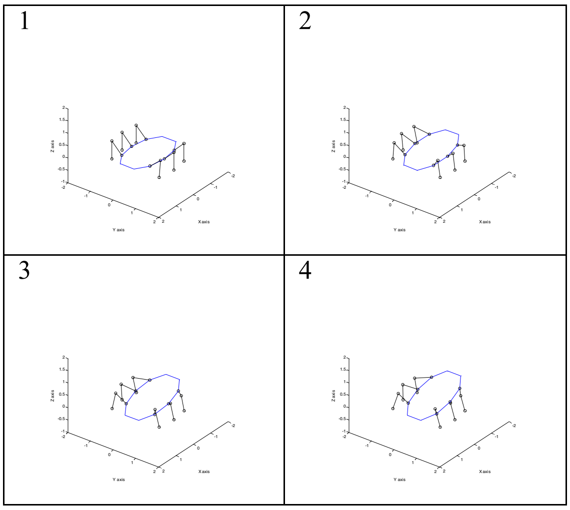


Fig. 14. Body contour for simulation

C. Application Strategy of Scanning Sonar

In order to minimize surface reverberation mentioned in chapter Ⅲ, the pitch inclination angle built around the scanning sonar should be offered. Hence, the body coordinate system should be shifted center of the sonar. In table Ⅳ, after being shifted, the results of CR200 posture controlling is indicated on X-Z plane and when CR200 is being controlled like this, it has pendular swings.

TABLE IV. RESULT OF POSTURE CONTROL SIMULATION IN X-Z PLANE



V. CONCLUSION

An application strategy of scanning sonar to get precise images with CR200 was embodied in this undertaking. First, the results of sea trial and calculated area of surface reverberation were compared and analyzed when using tripod within 15m depth. For the next step, how to calculate the desired pitch angle to control attitude on X-Z plane was explained and the results were analyzed when scanning sonar was operated with CR200. Finally, the posture control of CR200 on X-Z plane to utilize the sensor was shown by simulation in chapter Ⅳ.

In future works, advanced experiments that offer pitch inclination angle to CR200 and rotating sensor in all directions will be performed with calculated posture control angle on X-Z plane. If it would be applied to CR200, it could take a required pitch inclination angle pose consistently in shallow water. This method could be defined as "Hula hoop motion of CR200" because it is as like as hula-hooping shown in Fig. 15.

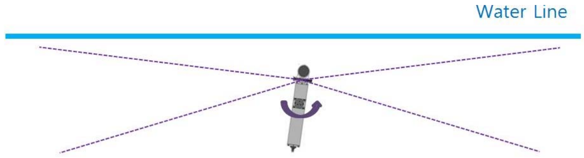


Fig. 15. Concept of hula hoop motion

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