Development Report:

Autonomous Underwater Vehicle "BOSS-A" for Acoustic and Visual Survey of Manganese Crusts

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[Received August 25, 2015; accepted December 8, 2015]

In order to effectively investigate the distribution and amount of cobalt-rich manganese crust (CRC), an autonomous underwater vehicle BOSS-A equipped with visual and acoustic instruments were developed. BOSS-A observes the seafloor along preset waypoints at a constant speed and altitude. Detailed 3D seafloor images can be obtained from the visual instrument, which employs a sheet laser and a camera. In addition, an acoustic instrument measures the CRC thickness beneath BOSS-A. The CRC at Katayama seamount was surveyed in February. The results visually presented the state and distribution of the CRC in this site and clarified the amount of the CRC. In the future, the authors will develop a more reliable thickness measurement method.

Keywords: autonomous underwater vehicle (AUV), manganese crust, 3D mapping

1. Introduction

The cobalt-rich manganese crust (CRC) that contains more cobalt and platinum than other manganese crusts is expected to be used as a mineral resource. However, the accurate amount of CRC in marine environments has not been determined because its distribution and thickness vary with the marine environment. In order to investigate the amount of CRC quantitatively, the authors have developed a thickness measurement device employing acoustic waves [1]. Investigation of the CRC using this system on a remotely operated vehicle (ROV) of the JAMSTEC partly clarified the amount of CRC in No.5 Takuyo seamount located south of Japan. However, it was difficult to maintain the ROV at constant altitude because its cable was pulled when the ship moved and swung with the tides and waves. Hence, the CRC thickness measurements were unsatisfactory.

In order to accurately and effectively examine the amount of CRC, the measurement device should meet the following conditions.

1) A constant altitude of 1.5 to 2.0 m should be maintained during observation.
2) Acoustic waves from the thickness measurement device should be incident vertically on the seafloor.
3) Crust distribution in the horizontal direction should be observed.

In this study, an autonomous underwater vehicle (AUV) BOSS-A, was developed in 2013 to equip an acoustic instrument fulfilling above functions. Unlike the ROV, the AUV is untethered and thus can stably navigate regardless of ship fluctuations [2]. **Fig. 1** shows the external appearance of BOSS-A. This paper describes the functions and observation methods of BOSS-A and reports CRC survey results for No.5 Takuyo and Katayama seamounts obtained using BOSS-A in 2015 (NT15-03 cruise).

2. Overview of AUV BOSS-A

A hovering type AUV BOSS-A (total length, 3.0 m; weight, 580 kg; and depth limit, 3,000 m), has four thrusters, and its maximum speed is 0.5 m/s. The AUV measures the distance from an obstacle by front scanning sonar, and thus is capable of avoiding obstacles. BOSS-A estimates self-location near the seafloor based on the ground speed obtained by the Doppler velocity log (DVL) and true bearing determined using a three-axis fiber optic gyroscope (FOG). At altitudes where the DVL is unavailable, BOSS-A determines self-location by using acoustic positioning device from the ship. The AUV automatically navigates along the preset waypoints and observes the CRC. Observation devices on the BOSS-A include a visual instrument for creating 3D seafloor images [3] and acoustic instrument for measuring the CRC thickness. Images obtained by the visual instrument are divided into reflection images of the sheet laser on the top and seafloor images of LED light on the bottom, as shown in **Fig. 2**. The relative distance between the AUV and the seafloor is geometrically calculated from the position on the laser light in images, and the seafloor shapes are esti-

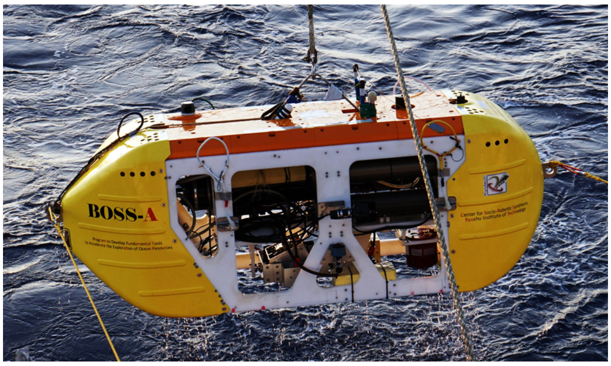

Fig. 1. AUV BOSS-A.

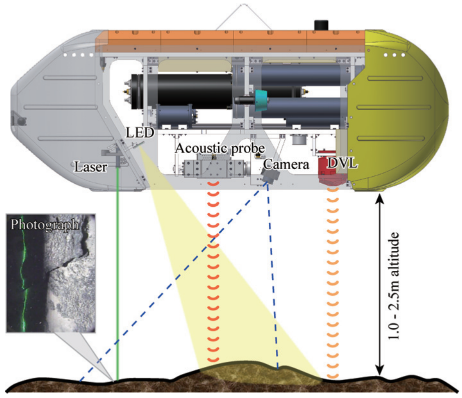

Fig. 2. Observation method.

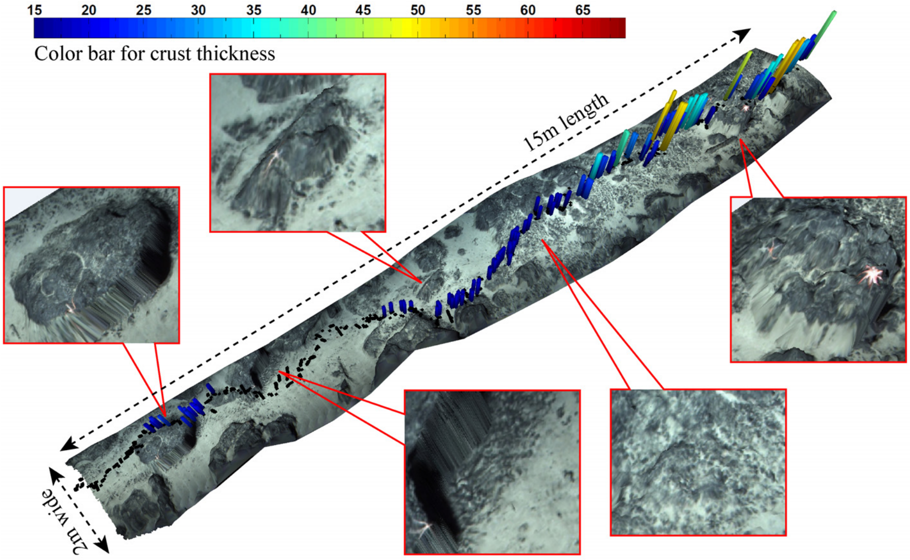

Fig. 3. 3D reconstruction of the seafloor of Katayama seamount.

mated based on its distance, the AUV's self-location and attitude data. A 3D seafloor image is created by adding color data of the seafloor in pixel presented in the bottom image to estimated seafloor topography. The acoustic instrument calculates the CRC thickness in millimeter by radiating acoustic waves with a narrow-beam width using the parametric effect and measuring the time lag between the acoustic waves reflecting on the seafloor surface and on the boundary surface of the bedrock. It is not necessary to frequently control the position and attitude of the BOSS-A because the direction of the acoustic probe is controlled using a gimbal device so that the instrument transmits acoustic waves vertically to the seafloor. The thickness of the rough CRC can be measured accurately by separating the waves reflected from the seafloor surface and the boundary surface of the bedrock because the instrument involves no side lobes or mechanical echoes.

3. Experimental Results

In order to study the exact distribution and amount of CRC, a survey was conducted using BOSS-A in the water depth of 1350 to 1550 m in No.5 Takuyo and Katayama seamount in February 2015 (NOT-03 cruise). BOSS-A cruised underwater for 16.0 h and successfully observed the seafloor for 4.5 h. **Fig. 3** shows 3D seafloor images for a 2×15 m area and the CRC thickness calculation results based on the observation data obtained at a constant altitude of 2.0 m. Because our acoustic instrument cannot accurately measure thickness of 15 mm or less, measurement values of 15 mm or less were indicated as 0. All the large black rocks in **Fig. 3** are the CRC exposed on the seafloor surface. The color bars indicate CRC thickness. The survey results show that the CRC in Katayama seamount is not as massive as a bedrock and has collapsed in some locations. The locations at a thickness of 50 mm or more are not on a black rock; they are likely to be measured incorrectly. Hence, reflection waves from the seafloor surface and the boundary layer cannot be separated owing to noise. If these values are errors, the thickness at those location are 15–45 mm. These results are highly valuable for understanding the CRC formation process, enabling the use of the CRC as a mineral resource and helping discover new CRC areas.

4. Conclusions

This paper describes the functions and observation method of BOSS-A, an AUV that simultaneously performs 3D measurements and CRC thickness measurements, and reports the results of CRC survey performed in February 2015. The results clarified the distribution and amount of CRC in Katayama seamount. However, the thickness measurement results included unreliable measurement values. Such unreliable measurement values can probably be excluded or modified by comparing these results with the values obtained from the generated 3D seafloor images because thick CRCs are more visible.

In the future, the authors will develop a reliable, accurate measurement method for CRC thickness by combining a visual instrument and an acoustic instrument. In addition, the CRC amount in No.5 Takuyo and Katayama seamount as whole will be determined using the developed measurement method.

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