Development of a Seabed Walking Platform for Ore Sample Drilling in Deep Sea Mining

Keisuke Watanabe
Department of Navigation and Ocean Engineering, Tokai University, 3-20-1 Orido Shimizu-ku
Shizuoka, 424-8610, Japan

E-mail: keisuke@tsc.u-tokai.ac.jp

Abstract

In deep-sea mineral resource development, exploratory drilling is indispensable for estimating the amount of resources. In order to reduce the cost of exploration, a system for drilling on the seabed is needed instead of a support vessel at sea. This exploration platform must be able to move along with the undulations of the seafloor and have a structure that supports the reaction force of the drilling. The authors have been studying an eight-legged drilling platform. This paper introduces the system configuration of an eight-legged walking robot.

Keywords: Deep sea mining, Exploration phase, In-situ drilling, Sea bed walking robot

1. Introduction

Acquiring mineral resources such as rare metals from the seabed has long been debated. However, a commercial seafloor mineral resource development project has not yet been realized. The reason for this is that although there is a technical problem that the mining system in the deep sea has not been established, there is also a big problem that the method of deposit exploration necessary for judging the economic feasibility of the project has not been established.

Currently, there is a track record of drilling to a depth of around 3000 m, and in the development of technologically mature offshore oil fields, the ratio of exploration costs to the entire project is becoming relatively small. For example, according to a report[1] by Norwegian Petroleum, "In 2020, the overall costs were around NOK 245 billion. Investments made up about 60 per cent of this, operating costs 25 per cent, and exploration costs about 10 per cent.". Nevertheless, a very large amount of money is spent, and it is expected that exploration costs will need to be kept lower in the development of seafloor mineral resources than in the development of offshore oil fields.

In offshore oil field development, the size of subsea reservoirs can be estimated by seismological exploration. Then, an exploration well will be drilled for the promising reservoir. There are two types of exploration wells. One is called wildcat wells, and the other is called appraisal wells. Wildcat wells are drilled to find out if hydrocarbons are really there beneath the seabed of the target area. Once the discovery has been approved, appraisal wells are drilled to obtain more data about the size and extent of the reservoir to estimate the feasibility.

On the other hand, in the development of seafloor mineral resources, it is impossible to see veins by seismic exploration. Therefore, it is necessary to carry out a large number of wildcat-like exploration to estimate the size and range of veins by obtaining actual ore samples. For exploration drilling, it is possible to use MODU (Mobile Offshore Drilling Unit), which is commonly used in offshore oil/gas field development. However, this method is not a good idea not only because of its high operation cost, but also because of the transportation of ore samples from the seabed to the ocean. This is because, in the case of crude oil, the underground pressure causes the fluid to blow up inside the riser, but the ore sample requires energy to be sucked up inside the riser pipe. Moreover, in this case, the ore sample needs to be made into fine particles and mixed with seawater to have fluidity. Therefore, in addition to the drilling device, it is necessary to install a crusher that finely crushes the drilled ore and a mixer that mixes the ore with seawater to enhance fluidity on the seabed or at the riser entrance.

Based on the above background, the author is studying a method of deploying a large number of in-situ type subsea drilling equipment and conducting exploration drilling at low cost without using MODUs. In this paper, the 8-legged walking robot currently under consideration is introduced[3].

2. The Concept of Eight-legged Walking Robot

As a method of moving the device for in-situ drilling on the seabed, a method using a thruster such as a navigation type underwater robot can be considered. However, in the drilling robot, it is necessary to increase its own weight enough to support the reaction force generated when drilling the seabed. When moving by a thruster, it is necessary to generate a buoyancy that cancels this own weight, and a buoyancy variable mechanism will be required. It is not easy to realize a variable buoyancy mechanism at deep water. Therefore, a walking platform that can move while supporting its own weight is suitable. Figure 1 shows the prototype design of the eight-legged robot. The robot consists of two decks that can slide in orthogonal XY directions. These are called Upper Deck (UD) and Lower Deck (LD), respectively. Each deck has four legs, each of which can slide up and down. As shown in Fig. 1, each leg is L1 to L4 and U1 to U4. Walking movement is realized as follows. While the UD legs U1 to U4 land and support their own weight, the LD legs L1 to L4 are lifted and the LD is slid. Also, by landing these legs, it supports the reaction force of drilling the seabed of the drill unit. The crawler-type drilling machine being developed by JOGMEC[2] is difficult to climb up and down the slope of the seabed. On the other hand, since this 8-legged robot can change the length of each leg, it can move even in a complicated seabed topography. That is, it is possible to move along the unevenness of the seafloor topography and to go up and down the slope. If the seabed is soft ground, it is necessary to devise a mud mat so that each leg is not trapped in the ground.

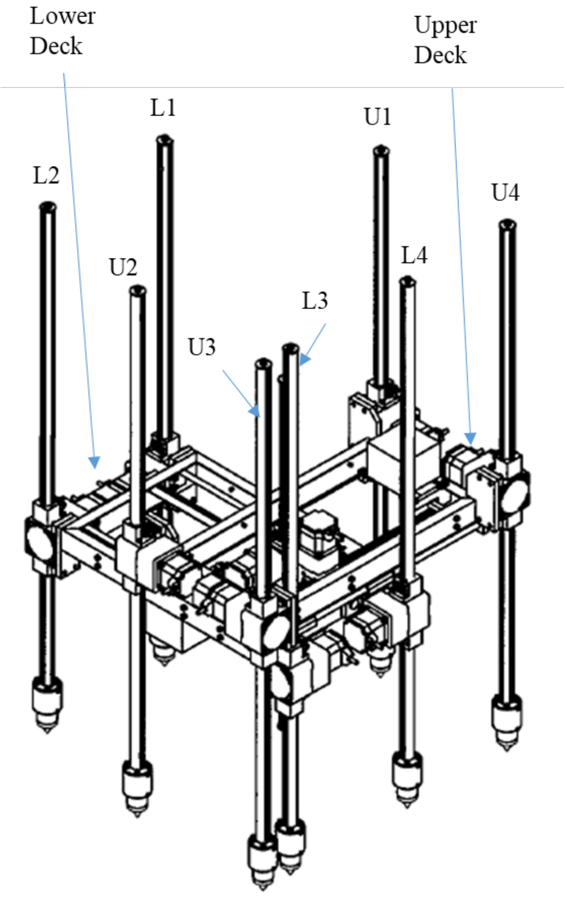

Fig. 1. Prototype design of the eight-legged robot.

The drilling unit is attached to the Upper Deck. The details of the drilling unit need to be further examined in the future, but the important functions required of this robot, including the drill unit, are as follows.

(1) Being able to collect the drilled ores so that they are not scattered in the sea.
(2) Automatically connect the drill pipes vertically to dig deeper.
(3) Equipped with drilling and moving power
(4) Being able to accurately detect the position on the seabed

In order to realize these functions, it is necessary to build experimental system and accumulate knowledge through experiments.

3. Experimental System for Walking Procedure

In order to study the walking algorithm of the 8-leg drilling platform, an experimental device as shown in Fig.

2 was manufactured. The motor was stored in a watertight container and an underwater walking experiment was conducted. An attitude (roll, pitch) sensor is attached to each deck, and the length of each leg is adjusted so that the deck is horizontal. In addition, a touch sensor is attached to the tip of each leg to know that it has touched the seabed.

As shown in Fig. 3, a slope was provided in the water tank, and obstacles were installed at the same time to realize unevenness. If the touch sensor detects the bottom of the sea, the leg descent is automatically stopped. The control algorithm is as follows. First, move from the start point toward the target point by a given distance in the X direction. The robot then moves a given Y-direction distance. In this experiment, we could not obtain a Yaw sensor that satisfies sufficient accuracy, so we did not consider the rotational motion around the Z axis. It was confirmed that it is possible to go up and down the slope very easily by using the touch sensor and the attitude sensor of the deck. Figure 4 shows the control menus of the developed interface. Each leg can be handled manually as well as automatically controlled to follow the given target point in the tank.

4. Some Experimental Results

Figure 5 and 6 show experimental results of walking experiment in the water tank. Figure 5 shows the zig zag walking result in the horizontal plane. As shown in the graph, the robot is controlled to move X-direction from -2000 mm to -300mm, while Y-direction from 500 mm to 750 mm. The step in the graph shows the slid distance of the deck. Figure 6 shows the slope ascending and descending experiment result. As shown in the graph, it moved along the plate placed on the tank floor in Fig.3. The grey points show the Z directional distance, which means the height. It goes up from around -1400 mm to -1000 mm and goes down from a-1000 mm to -1400 mm, which means its slope walking succeeded. In this experiment, as shown in Fig. 3, four blue steps and a step by a bar in the middle of the slope were prepared. Despite these steps, we were able to confirm that our robot could walk with a very simple algorithm.

As can be seen from Fig. 2, there are many cables connecting the motors and they are relatively heavy, and in a navigation type underwater robot, the cables are at a level that hinders movement. However, since this robot is a mechanism in which the legs land on the bottom and support its own weight, no adverse effect of the cable on the walking was observed. I think this is a big advantage of this concept.

Fig. 2. Schematic View of Experimental Setup.

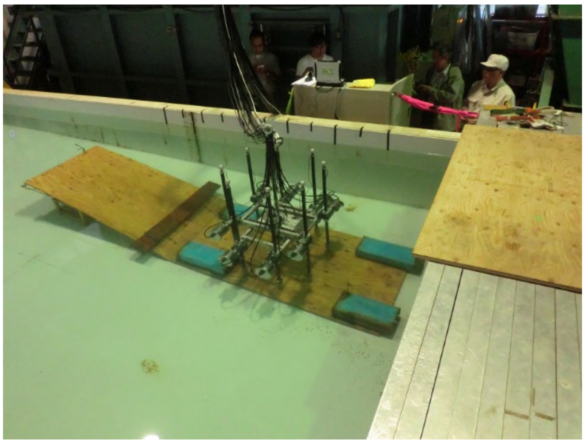

Fig. 3. Basin Experimental Setup with a Slope

5. Discussions

As a result of this tank experiment, some future issues were found. It goes without saying that the length of the foot is closely related to the ability to climb a slope. The difference in height between the front and rear legs vs the length of the deck determine the angle of inclination of the slope that can be climbed.

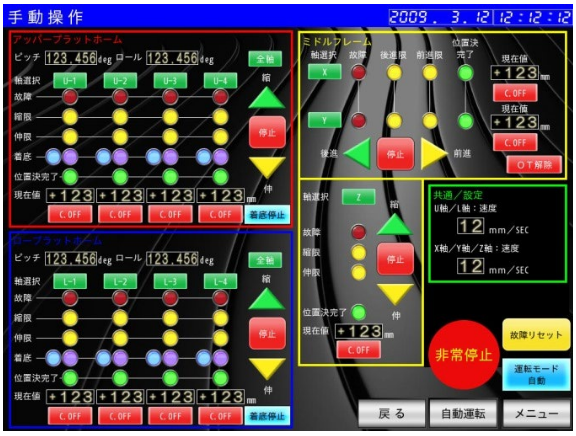

Fig. 4. Control Interface on the PC

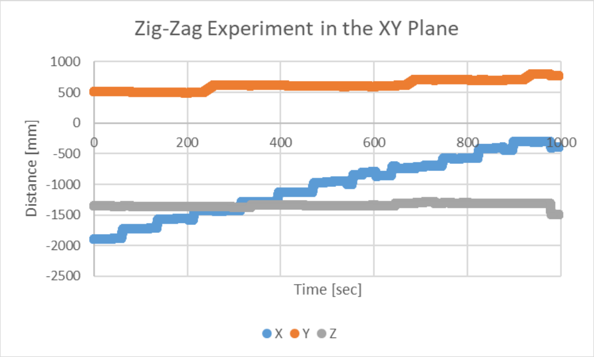

Fig. 5. Zig Zag Walking Experiment Result

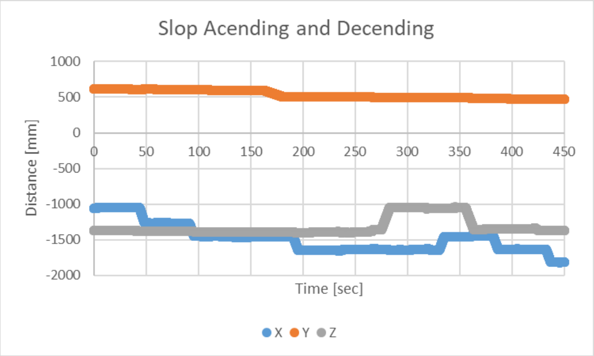

Fig. 6. Slope Ascending and Descending Result

Therefore, it is important for designing the platform size to survey the topography of the seafloor of the area that is planned to be explored in advance.

In addition, the platform cannot rotate around the z-axis. In order to change the direction of travel on the seafloor, it is necessary to consider a mechanism that allows rotation. Furthermore, it is necessary to consider how to install the robot in the deep sea.

6. Conclusion

In this paper, we introduced the in-situ type subsea drilling walking robot that we are currently studying, and introduced the underwater walking experiment in the tank. The robot has two sliding decks and eight legs, and while the four legs support their own weight, the other four legs slide and move. We constructed a water tank experiment system, conducted an experiment to walk zigzag in a plane, and an experiment to go up and down a slope, and confirmed the basic performance. The experiment was successful, and it was confirmed that a simple algorithm can make the platform move to the target point. In addition, some new research challenges have been discovered that should be investigated further. For example, it is difficult to increase the walking speed because it takes time to raise and lower the legs, and it is also difficult to rotate around the vertical axis. However, through experience in the experiments, it was confirmed that this concept is suitable for in-situ drilling because it can support the reaction force of drilling as well as various devices can be mounted on the deck.

Acknowledgements

This work was supported by JSPS KAKENHI Grant Number 18K04585.

References

1. https://www.norskpetroleum.no/en/economy/investments-operating-costs/.
2. N. Okamoto, S. Shiokawa, S. Kawano, H. Sakurai, N. Yamaji and M. Kurihara, "Current Status of Japan's Activities for Deep-Sea Commercial Mining Campaign," 2018 OCEANS - MTS/IEEE Kobe Techno-Oceans (OTO), 2018, pp. 1-7.
3. Y. Watanabe, K. Watanabe, H. Suzuki, T. Ooshima, Y. Tsukamoto, "Research and Development of a Self-Walking Vertical Mining System Using DTH Drilling Unit and the Scale Model Test", OMAE2019-95394, 2019

Authors Introduction

Dr. Keisuke Watanabe

He is a Professor of School of Marine Science and Technology, Tokai University in Japan. He received his B.E., M.E. and ph.D. degrees from the Dept. of Naval Architecture and Ocean Engineering, The University of Tokyo, Japan in 1991,1993 and 1996. His research interest is autonomous marine vehicles application.