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Research Article

Tank Experiment of a Seabed Walking Platform Model for Subsea Mining Exploration

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ABSTRACT

In the near future, deep-sea mineral resource development will be possible to be commercialized. To minimize the CAPEX of the project, estimation of deposit quality is critically important and exploratory drilling is indispensable for estimating the amount of resources. To reduce the cost of exploratory drilling, we are going to develop a system of seabed drilling which can move on the seabed by itself without a support vessel on the 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 our tank test system and some results of tank experiment.

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 which is 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 in the development of technologically mature offshore oil fields and the ratio of exploration cost to the entire project is becoming relatively smaller. 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 we believe that exploration cost will need to be kept much smaller 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 explorations 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

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offshore oil/gas field development. However, this method is not a good idea not only because of its high operational 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 the ore from the seabed to the top facility through inside the riser pipe [2]. 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 [3,4,5,6]. In this paper, a tank experiment of the 8-legged walking robot currently under consideration is introduced.

2. The Concept of Eight-legged Walking Robot

As a method of moving the device for in-situ drilling on the seabed, a traditional navigation type underwater vehicle can be considered. However, in the drilling robot, it is necessary to increase its own weight enough to support the reaction force generated by the drill into 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. As the reaction force will be at least several hundred kN, it is not easy to realize a variable buoyancy mechanism to yield such force at deep water. Therefore, a walking platform that can move while supporting its own weight is suitable.

There have been many researches related to walking robots design and control as a mobile platform in the rough terrain on land [7,8,9]. However, conventionally, crawler-type robots have been the main method of moving on the seabed [10,11,12] and there has not been much research on walking-type robots.

Figure 1 shows the prototype design of the eight-legged robot. Figure 2 shows the deck layout and dimensions. 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.

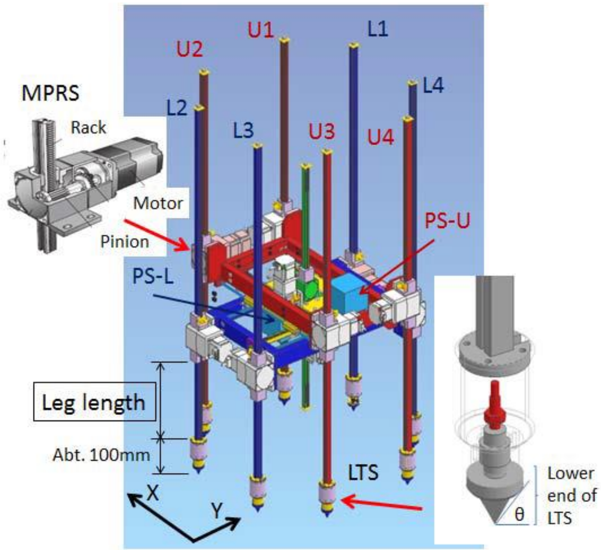


Fig. 1 Prototype design of the eight-legged robot.

As shown in Figure 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 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.

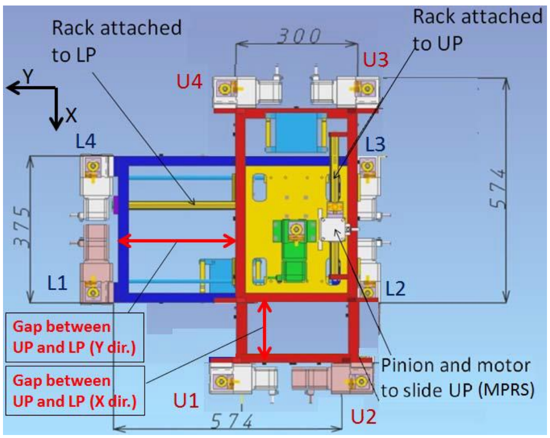


Fig. 2 Deck layout and dimensions.

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. Tank Experiment System

In order to study the walking algorithm of the 8-leg drilling platform, an experimental device as shown in Figure 3 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.

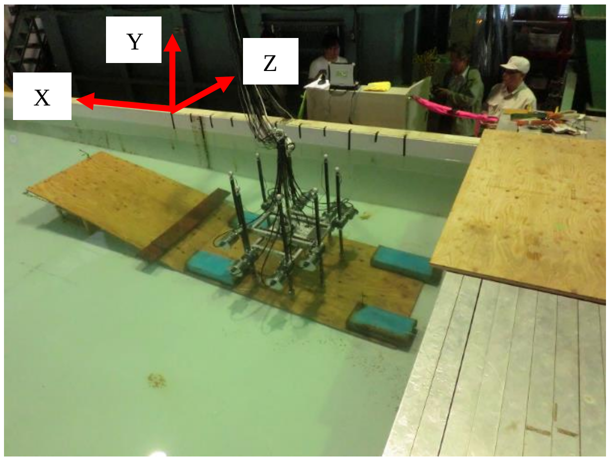
The purpose of this experiment is to confirm that the robot can walk even if obstacles are placed at the bottom of the tank and that the robot can climb up and down a slope of about 30 degrees.

As shown in Figure 4, a slope was installed in the tank and several blocks were placed at the bottom of the tank to achieve the unevenness.

In this experiment, the coordinates of the robot in the tank were calculated from the land using a 3D image processing system. In the actual system on the seafloor, a positioning system such as LBL should be installed on the seafloor. The coordinate system is shown in Figure 4.

The control algorithm is basically sequence control. First, from the starting point, the robot moves a given distance in the X or Z direction toward the target point. When climbing a slope, it automatically climbs the slope because the leg stops when it senses the slope as it lowers the leg that was lifted to move forward. The same is true when descending a slope. Currently, it is not possible to control both the X and Z directions at the same time, and the robot will always move forward in either the X or Z

direction. Vertical movement of each leg was performed



by servo motors with a feedback function.

Fig. 3 Tank experiment robot schematic view

Fig. 4 Basin experimental setup with a slope

When the amount of stage movement in the X direction is set to ΔX and the possible height of one leg is ΔH, the theoretical tilt angle θ, which allows climbing up and down, is given as $\tan\theta = \Delta H/\Delta X$.

In this experiment, the robot is not equipped with a sensor to detect the angle of inclination of the slope in front of it.

Therefore, each leg was raised to ΔH, the maximum height of the movable part, and moved a predetermined distance in the X direction. This method would raise the legs to an unnecessary height when the tilt angle is small, which is inefficient in terms of both time and energy. Therefore, it was found that in the actual system, the slope angle of the slope in front of the robot should be measured and the legs should be raised or lowered by the minimum necessary height.

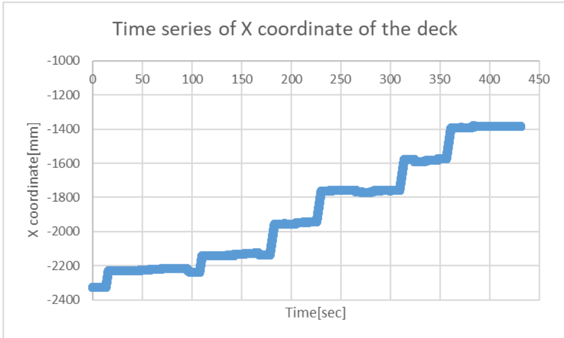
A touch sensor attached to the tip of the leg is very effective. When the touch sensor detects the seabed, the descent of the legs is automatically stopped. Despite the simplicity of the mechanism, the touch sensor and the attitude sensor on the deck enable the robot to keep the deck level even on uneven seafloors, and the robot can ascend and descend slopes very easily.

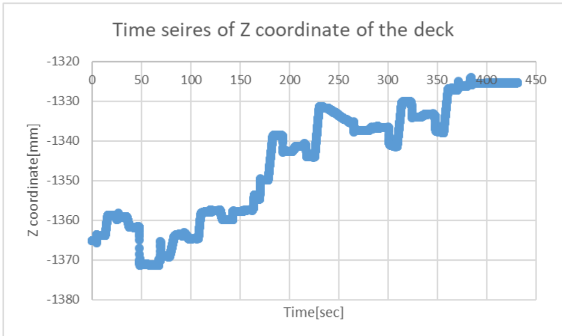
4. Experimental Results

Figures 5 through 8 show the results of the tank experiment. Figure 5 shows the Y coordinate, i.e., the amount of movement of the height of the deck section. The vertical and horizontal axes of the figure represent the amount of movement in the Y direction and time, respectively. The unevenness of the graph from the start to about 240 seconds reflects the unevenness placed on the bottom of the tank. From about 240 to 260 seconds, the graph shows the movement up the slope. In this experiment, the robot was only able to climb a distance of about 100 mm due to the size limitation of the tank, but we have confirmed that the same robot can climb a longer distance and a 45-degree slope in land-based experiments.

Figure 6 shows the time series of X coordinate of the deck during the experiment of climbing a slope. It started from around -2350 mm and moved around 1000 mm. Based on the results of this experiment, the forward speed is about 2.8 mm/sec. Assuming that this model is 1/100 scale, the speed of the actual machine is 28 mm/sec, calculated from Froude's law of similarity. This speed observed here will be too slow in practical use. The forward speed was physically determined by the control speed of the servomotor employed in this study. The forward speed also depends on the distance the legs are raised. We found that it is necessary to consider how to increase the forward speed while taking these points into account in the future.

Figure 7 shows the time series of Z coordinate of the deck. It started from around -1365mm and moved around 40mm, which means the robot moved almost only X direction along the base on the tank floor shown in the Figure 4. In this experiment, the movement was programmed only in the X direction and not in the Z direction. Therefore, the fluctuation observed here is considered to be caused by the unevenness of the bottom,





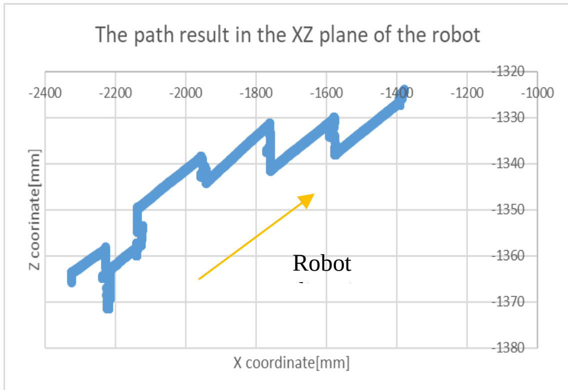


Fig. 8 Robot trajectory in the XZ plane

implement feedback control in the future, it was confirmed that the robot has, in principle, higher straight-line performance than a navigational robot.

Figure 8 shows the XZ plane path result. Considering the fact that the movement over the unevenness of the bottom and the slope, this fluctuation is considered to be very small, and the walking method presented by this system is considered to be effective in the development of seafloor mineral resources.

5. Conclusion

In this paper, we introduced an in-situ type submarine drilling walking robot and conducted an underwater walking experiment in a tank. We confirmed that the platform can be moved to the target point with a simple algorithm even if the seafloor is uneven or sloped. It turns out that the designed robot can climb sloping terrain with a very simple algorithm. In addition, we found that the straight-line performance of this system is much better than navigation type robots. As a result of this tank experiment, some future problems were also found. For example, in designing the shape of the platform, it is important to survey the seafloor topography of the planned exploration site in advance. This is because the maximum slope angle that the robot can climb is determined by the ratio of the height difference between the front and rear legs to the length of the platform deck. Since it raises and lowers its legs while searching for the hardness of the seabed, its forward moving speed is very slow. In addition, we need to implement a rotating mechanism to change direction on the ocean floor. These issues need to be resolved in the future.

As a whole, it was confirmed through experiments that this concept is suitable for drilling for seabed resource development because it can support the reaction force during drilling and various devices can be mounted on the deck.

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Author Introduction

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