Flipper Type Crawler System for Running on the Irregular Seafloor

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***Abstract*- Flipper type crawler system gives advantages when running on the irregular seafloor and when working on the seafloor. We developed a small size ROV (remotely operated vehicle) equipped with the flipper type crawler systems and conducted the experiments using it in a water tank and on the seafloor to observe its advantages. In the experiments in the water tank, the ROV was tested to run on the tilting table changing an angle and also to run over bumps nailed onto the top board of the tilting table. In the experiments on the seafloor, the ROV could evacuate from the condition that the crawler system was slightly submerged in the sand. Also the ROV could run and climb up the bumps. This paper describes the developed flipper type crawler systems and its advantages by describing the results of the experiments in the water tank and on the seafloor.**

I. INTRODUCTION

Japan Agency for Marine-Earth Science and Technology (JAMSTEC) has developed the ROV ABISMO (Automatic Bottom Inspection and Sampling Mobile) [1] as shown in Figure 1, which is capable of diving to the deepest sea and obtaining sediment samples from the sea floor. The ABISMO actually succeeded in dives deeper than 10,000m in the Marian Trench and recorded 10,257m dive. The ABISMO has, among its features, a crawler system in addition to thrusters as a mobility function when moving on the seabed [2]. However, further development was needed for ABISMO to move on the seafloor with the crawler system. And JAMSTEC has also started research and development activities for the next generation deep-sea exploration technology in which crawler system to observe on the sea floor is listed.

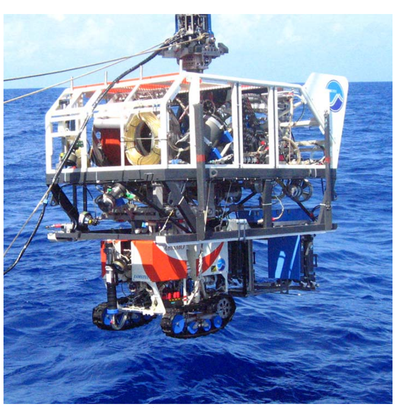

Figure 1. Picture of ABISMO.

Mobility characteristic in steady running was theoretically and experimentally investigated [3][4]. As a result, a lightweight ROV is apt to run in wheelie in some cases in spite of the fact that the vehicle could run stably on land. It is influenced by the weight and buoyant force as well as the center of gravity and the center of buoyancy. Especially when the weight of the vehicle was less, the stability got worse. On the other hand, the vehicle ran stably when the vehicle had an adequate weight and an adequate center of gravity. The theory gives the discrimination chart of stable running, which means "no wheelie running", for the center of gravity and the center of buoyancy. Then, it is necessary to design the center of gravity and the center of buoyancy to be in "stable area". However, one of the important matters is that the ROV runs forward and also backward. It results in changing the discrimination line. And it sometimes makes the center of the gravity and the center of buoyancy to be outside of "stable area". In order to increase the stable area and also to change meaningly the center of gravity, we have proposed a method to virtually increase the weight and to change the center of gravity by using vertical thrusters. And experiments confirmed advantageous effect [5].

In order to achieve adequate mobility of the crawler systems when running on the seafloor, an additional advanced mechanism is needed because the seafloor is irregular, bumpy or sloping terrain. There is a limited height of a bump to run or climb up. Generally the crawler cannot clime up a higher bump than a half of the diameter of a forward wheel of a crawler system. One of the solutions is to possess a function of a rotating mechanism on the crawler, which can rotate the crawler system itself, called flipper system. So, we develop a flipper type crawler system consisting of 4 crawlers and flipper system for each crawler to run on the irregular seafloor. The flipper type crawler system gives an advantage not only when running on the irregular seafloor but also when working on the seafloor. It is important to keep the attitude of the ROV to prevent fall down especially when holding a heavy sample by a manipulator or being subjected to a reaction force of heavy duty. In this situation, flipper type crawler exercises the advantage because the crawler can be rolled out, then the lever become to be wide.

II. Flipper Type Crawler System

A. Mechanism of Flipper Type Crawler System

Flipper type crawler system is a crawler system processing the function to rotate the crawler itself 360 degrees as shown in Figure 2.

As described above, the crawler system generally cannot run over a higher bump than the half of the crawler height. On the other hand, flipper type crawler system is cable of running over such a higher bump by activating the flipper mechanism. For example, consider the running of an ROV having the 4 crawlers with a flipper system for each crawler. When the ROV faces the bump as shown in Figure 2, the flipper will activate to rotate the front crawlers and to mount them on the bump. The rear crawlers may be operated rolling out to keep the attitude of the ROV and to prevent it from falling down.

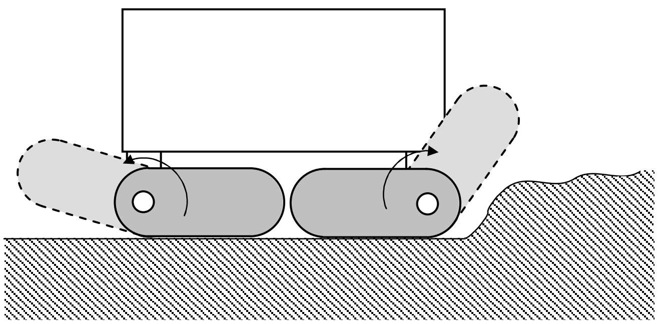

Figure 2. Schematic of a flipper type crawler system.

B. Mechanism Dual-Row Flipper Crawler System

There is a concern that the ROV body may run on an obstacle and reaches a deadlock when rolling out the crawlers. Actually it was observed during the experiments. Also, when activating the flipper system, ground contact area will become smaller in some cases, which will result in worse mobility.

One of the solutions to redeem such concerns is to add additional normal crawlers without flipper mechanism outside the flipper type crawler system. The outside normal crawlers can be designed to be driven by the motors for the flipper crawlers. This means that no additional motors are needed. The outer normal crawlers are dismountable.

C. Small-Size ROV Equipped with Flipper Crawler Systems

A small-size ROV with the flipper crawler systems is developed. Crawler system, the flipper type crawler which is called single-row flipper crawler to be distinguishable shown in Figure 3 or the dual-row flipper system shown in Figure 4 as described above, or a normal crawler described in [7] is changeable.

As described above, the same motors are used for both the flipper type crawler system and the dual-row flipper crawler system. Also, although other types of motors are used for normal crawler system, the same motor driver is used. It is of course a better engineering because a basic part of the control software of crawler systems can be the same.

Table 1 shows principal specifications. The ROV is developed only for experiments of crawler system. So, the related depth for each component and the cable length are designed for shallow water at this moment.

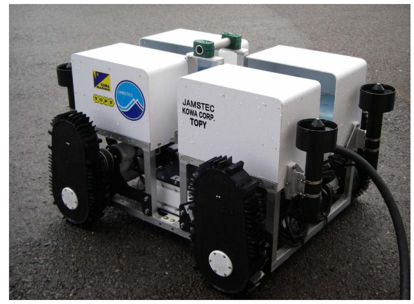

Figure 3. The ROV equipped with the single-row flipper crawler system.

Figure 4. The ROV equipped with the dual-row flipper crawler system.

TABLE 1
Principal Specification of the Small-Size ROV and the Flipper Crawler Systems

Items	Specification
Dimensions	<body> - 600mm (length excluding the crawler system) - 400mm (width excluding the crawler system) - 410mm (height excluding the crawler system) <with the Single-Row Flipper Crawler> - 606mm (overall length: crawlers are retracted) - 628mm (overall width) - 495mm, 508mm, 526mm (height, crawler fixing position is changeable.) <with the Dual-Row Flipper Crawler> - 652mm (overall length: crawlers are retracted) - 764mm (overall width) - 501mm, 514mm, 532mm (height, crawler fixing position is changeable.)
Thrusters	4 x 48 W motor with an encoder. Installation position can be changed.
Crawler systems	4 x 150 W crawler motor with an encoder. 4 x 150 W flipper motor with an encoder and a potentiometer.
Weight in air	44.3 kgf (434 N) with single-row flipper crawler 51.5 kgf(505 N) with dual-row flipper crawler
Buoyancy in seawater	20.3 kgf (199 N) with single-row flipper crawler 24.0 kgf (235 N) with dual-row flipper crawler without buoyancy materials

D. *Preliminary Simulation of Running Characteristics of Flipper Type Crawler Systems*

Preliminary simulation of running characteristics of the flipper type crawler in water was conducted [7] utilizing the Open Dynamics Engine (ODE) which is an open source, high performance library for simulating rigid body dynamics. In this simulation the ROV with 4 flipper crawlers or normal crawlers is modeled as shown in Figure 5. To simulate the condition in water, a buoyant force is model as body force in a direction opposite to the gravity and also a virtual body is fit on the fore end of the ROV on which a force simulated as a water resistance force in a direction opposite to running is acted. Also, a vertical force can be acted on the virtual body simulated as an object for example which grabbed by a manipulator.

As preliminary simulation, running on land and in water was simulated changing an angle of the flipper and the center of the buoyant force or the gravity. Even in the same condition of the ROV, running characteristics is different between on land and in water as shown in Figure 6 due to the buoyant force and the water resistance. The preliminary simulation reveals that mobility of the crawler in water is not same as the one on land and an additional investigation of mobility is needed. Also, simulation of running by the normal crawler in addition to by the flipper crawlers was conducted. And the advantage of the flipper crawler system was conformed. At this moment, running over an obstacle or on the irregular seafloor has not been simulated. Further development of the simulator is scheduled.

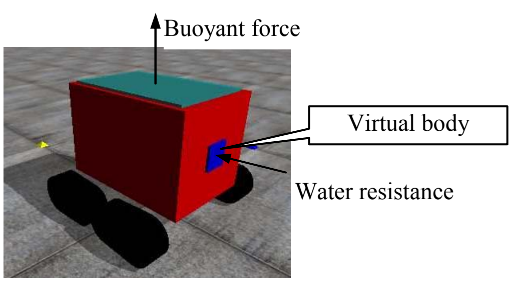

Figure 5. Model of the ROV with crawler system running in water

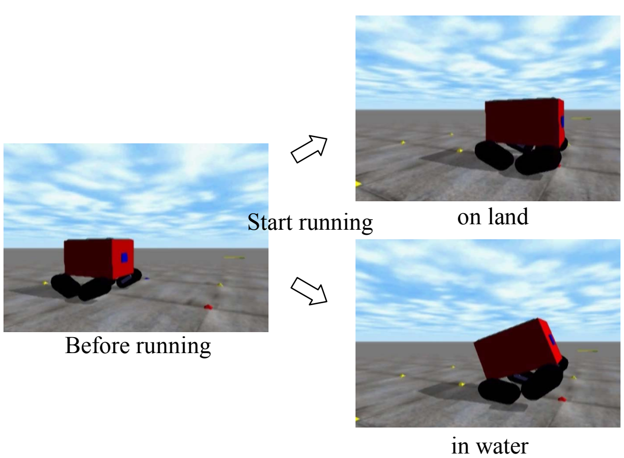

Figure 6. Simulation of running in water

III. EXPERIMENTS

A. *Experiments of Running in a Water Tank*

Experiments were conducted in a water tank of JAMSTEC.

A tilt table which angle can be changeable was set on the bottom of the water tank as shown in Figure 7. A top board was slippery-painted, which means there was low friction coefficient between the board and the crawler. To increase the friction coefficient, a carpet put down on the board. Also, blocks of logs having a diameter of about 10cm were put down on it simulated as the harsh irregular seafloor.

Mobility is of course affected by the weight and the center of gravity of the ROV. Generally describing, the ROV with the flipper crawler systems could run on the tilt table with carpet having an angle of 30 degrees. On the other hand, it was difficult to run tilt table with the slippery-painted board having an angle of 30 degrees because the crawler slipped. During running on the block of logs, advantage of the flipper crawler system was obviously observed. The ROV with normal crawler system could not run on just a log. On the other hand, The ROV with the flipper crawler systems could run over a log easily. However it could not run on the block of logs shown in Figure 9 because it was too loose for the crawler to have an enough grip force.

Figure 7. Tilt table with the blocks of logs in the water tank.

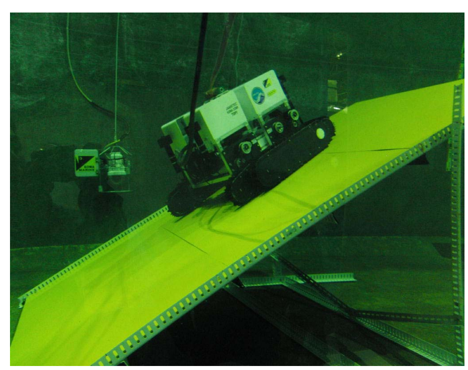

Figure 8. Running on the tilt table tilted 30 degrees in the water tank.

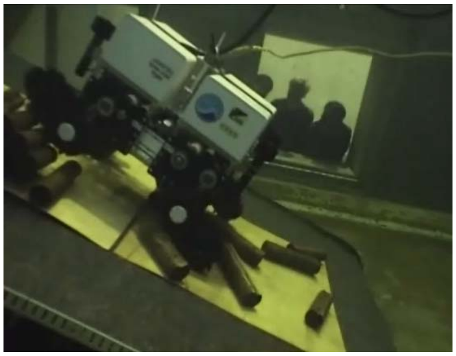

Figure 9. Running on the block of logs in the water tank.

B. *Experiments of Running on the Seafloor*

Experiments were conducted at the sea of less than 10m water depth to confirm the mobility of the crawler systems on the irregular seafloor. There were sand seafloor, inclined area and rock area with inclination.

The flipper crawler enabled evacuating from the condition that the ROV was slightly submerged in the sand or was swept off as shown in Figure 10. It is one of the advantages of the flipper crawler system.

It is obvious from the experiment in a water tank that the ROV with normal crawler could not run on the rock seafloor. On the other hand, the ROV with the flipper crawlers could run on the rock seafloor by operating the flipper mechanism as shown in Figure 11.

Figure 10. Evacuating from the condition that the ROV was slightly sink in sand seafloor.

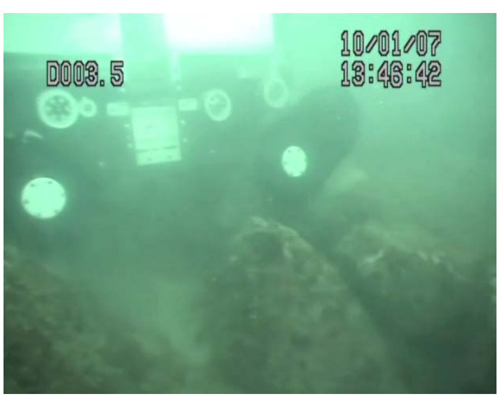

Figure 11. Running on the rock area at sea.

IV. CONCLUSIONS

We develop the flipper type crawler systems, the single-row flipper crawler system and the dual-row flipper crawler system. The advantages were obviously observed in the experiments in the water tank and at sea.

Generally, the normal crawler cannot run on a higher obstacle than a half of the crawler height. On the other hand, the flipper crawler has the function to rotate the crawlers themselves. It enables to run over higher obstacle. In the experiments in the water tank, the ROV with the flipper crawler systems could run on the tilt table with logs tilted 30 degrees. In the experiments at sea, the ROV with the flipper crawler could run on the irregular sand seafloor and also on the rock seafloor.

We will continue the experiments to observe and confirm the advantages of the flipper system further. We have also been developing a bigger flipper crawler system for the vehicle of ABISMO.

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