Deep-sea Drone with Spherical Ultrasonic Motors

Shigeki Toyama and Uichi Nishizawa

Abstract—**The deep sea of the 4,000m grade is a treasure house of resources. However, there are no precise maps about the sea bottom shape. So, the authors have developed deep-sea drone with functions to make sensing marine bottom and make maps of the 4,000m depth grades. The drone shape durable in the deep sea is only a sphere. The authors have made a prototype of deep-sea drone by use of spherical ultrasonic motors. The authors have succeeded in driving it in underwater.**

Index Terms—**Ultrasonic motor, deep sea, drone, and spherical motor.**

I. Introduction

The mineral resources in the sea near the shore are confirmed to be fertile by a past investigation. However, that of the deep-sea of 4,000 m or deeper is not investigated due to the harsh environment. Each country advocates a strategic innovation creation program and develops the diving investigation apparatus for the deep sea. Particularly, the technology development of Europe and America has advanced about the autonomous underwater vehicle (AUV) for military affairs and the national defense purpose. However, their main targets are the shallower sea than 200m. An AUV oriented for the deep-sea of the ocean has not yet reached the true operation.

The authors have developed the spherical ultrasonic motor for the water use as an available motor in the deep sea. A purpose of this study is to investigate properties of the spherical surface ultrasonic motor in water and make prototype of a deep-sea drone by use of it. Finally, the authors have made experiments to drive the drone in water successfully.

II. Concept of Deep-Sea drone and Spherical Ultrasonic Motor

The average depth of the oceans of the earth is around 4,000m. In the deep-sea of 4,000 m or deeper, a deep-sea submersible boat takes several hundreds atmospheric pressure. The tolerable shape is a sphere to resist the high pressure. So a drone and a submarine for the deep sea should be designed based on a sphere shape. The authors have developed the spherical ultrasonic motor [1].

The spherical ultrasonic motor has simple structure of only two components: a spherical rotor and three stators [2]. The three stators keep the rotor firmly in the center. The characteristics about the rotational speed and the output torque are adjustable by tuning the clamping force between them. As it has three rotational degree of freedom in one joint, the volume efficiency of the drone is very high.

Fig. 1. Open type of spherical ultrasonic motor.

The simple design of a deep-sea drone by spherical ultrasonic motor is shown in Fig. 2 (all spherical motor type). The drone consists of four spherical motors. The top two motors have cameras, sensors and computers inside the rotors. They are rotating and sensing deep sea. The center motor is not rotating. It has long life batteries for the motors, GPS, accelerometer and iridium mobile phone. The bottom motor is propelling the fins for driving to any direction. All motors are connected by Wi-Fi to communicate each other.

Fig. 2. Image of Deep-sea drone.

III. Waterproof of Spheical Ultrasonic Motor

A. Problems in Water Use of Ultrasonic Motor

There are two problems about the ultrasonic motor in water. One is waterproof treatment. It is also important from

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the view point of deterioration prevention of the stators and the rotor in sea. Another problem is a contact problem of the stators and the rotor. An ultrasonic motor is working by the frictional force [3]-[5]. However, in case of water use, a very thin water film (submicron meter order) is generated between the stators and the rotor. It prevents the driving force transmitted from the stators to the rotor. It might induce unstable rotation or no rotation. This is a very thin film but it has strong elasticity. It is difficult to remove it perfectly. The authors has fabricated some narrow teeth on the surface of the stators to set water free to the teeth ditch. Adding that, the authors has made rough on the surface of the stators to prevent water streamline flow.

B. Basic Experiments of the Spherical Ultrasonic Motor in Water

First, the motor should be waterproof treated. All electrodes have been covered by silicon. Next, the waterproof material has been treated to the stators and the rotor by spray type poly vinyl resin. It produce very thin anti-water layer on the surfaces. It aims to enable the motor to rotate smoothly.

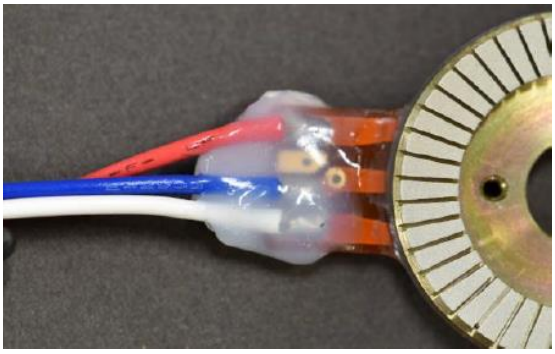

Fig. 3. Waterproof treatment on electrode.

Then, one pair of a stator and a rotor was set in water and the impedance of the stator at resonant was measured. Comparing it to that in air, it becomes much larger. This indicates that the motor in water requires higher driving voltage than in air. Next, the authors have made experiments about the effect of waterproof to the resonant phenomenon. The impedance shows that it has clear resonant characteristics in water. So, good maneuverability of the motor is expected.

In case of no treatment of waterproof about both stators and rotor, the motor shows poor maneuverability and unstable rotation. However, when either one of them or both were treated, the motor was working well. The optimal driving frequency was four kHz sifted lower than in the air. It means that the stator vibrates with surrounding water and the virtual mass of the stator is increasing due to the additional surrounding water mass.

Furthermore, the authors have evaluated the rotor materials of polycarbonate, ABS resin and acrylic material. They have shown mostly same performance.

Finally, the authors have investigated the effect of a rectangular edge stator and round edge type one. The rectangular edge contacts circle line with the rotor. The round one keeps smooth contact with narrow area of the rotor. The edge type might generate no water film but poor transmission of force. On the other hand, the round type might be easy to suffer from water film but keep stable contact with the rotor. The experiments have indicated that the edge type shows unstable rotation, but the round type is working well in water. The authors have adopted the round type.

Based on these experiments, the motor working in the air can be also working well in water when even electrode and stators waterproof are treated.

C. Characteristics of the Spherical Ultrasonic Motor in Water

The authors have measured the rotational speed of the motor in water, changing contact force of the rotor and the stator every 0.5 kgf from 1.0 kgf to 6.0 kgf. The experimental apparatus is shown in Fig. 5. The results are shown in TABLE I. For comparison, the output torque in the air is also shown. As the contact force is increasing, the rotational speed is decreasing. The results are nearly same in water and the air. However, the motor in water cannot work in case of low contact force.

The authors have also measured the output torque. The results are shown in TABLE II. Comparing to that in the air, the torque is reduced to about 20 percent. It is because that the coefficient of friction becomes lower due to the water film. Adding that, the impedance in water is higher than in air. When applying higher voltage and larger contact force, the larger output torque is expected in water.

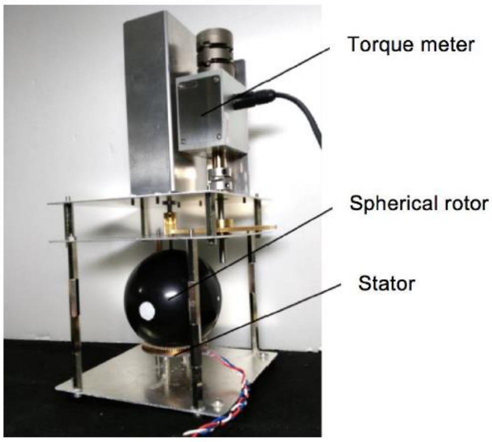

Fig. 5. Measurement equipment of the motor.

TABLE I: ROTATIONAL SPEED VS PRESSING FORCE

Pressing force [kg^f]	Rotational speed [rpm]	
	Air	Water
1.0	99	
1.5	90	
2.0	82	
2.5	79	
3.0	81	
3.5	77	72
4.0	77	76
4.5	75	83
5.0	72	78
6.0	65	72

TABLE II: OUTPUT TORQUE VS PRESSING FORCE

Pressing force [kgf]	Torque [N・mm]	
	Air	Water
1.0	42.0	
1.5	70.0	
2.0	82.8	
2.5	115.5	
3.0	143.5	
3.5	177.3	10.5
4.0	196.0	19.8
4.5	215.8	30.3
5.0	252.0	37.3
6.0	270.7	50.2

IV. PROTOTYPE DEEP-SEA DRONE WITH TWO SPHERICAL ULTRASONIC MOTOS

At first stage of developing a prototype drone, the authors have made a spherical ultrasonic motor for a deep-sea drone (Fig. 6). They are working well in water. Fig. 7 shows the prototype of a deep-sea drone. It has two spherical motors: one is for controlling the fins and another is for measuring the shape of sea bottom.

Fig. 6. Rotation experiments in water (left ABS rotor, right acrylic rotor).

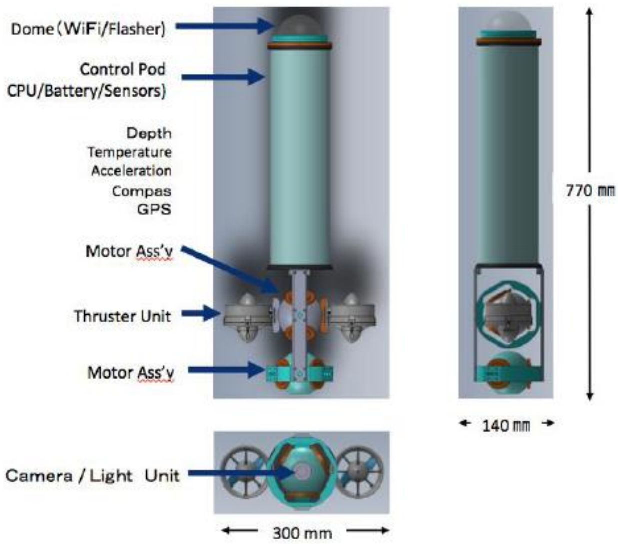

Fig. 7. Prototype of deep-sea drone with two spherical ultrasonic motors.

However, the new drive circuits of the motors are not small enough to install inside the drone at the first stage. So the drone in water has to be connected with cables of power supply and driving signal lines. In the swimming pool, it showed an excellent performance (Fig. 8).

In the near future, the authors have a plan that they will work as follows (Fig. 9); the deep-sea drones make a group robot of several million robots. They are dropped from a mother ship. They keep vertical posture and go down to the bottom controlling fins by a spherical ultrasonic motor. At the bottom, they measure the shape of the bottom, sea flow and the temperature and so on. After that, they come back to the sea surface. It takes about one hour to finish all works.

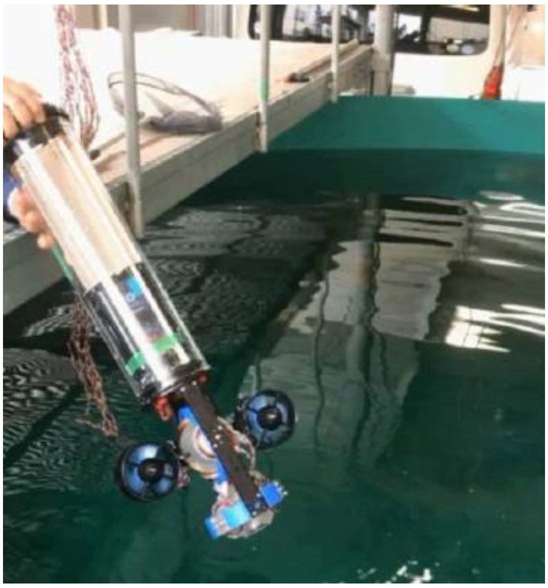

Fig. 8. Prototype drone in the deep-water pool.

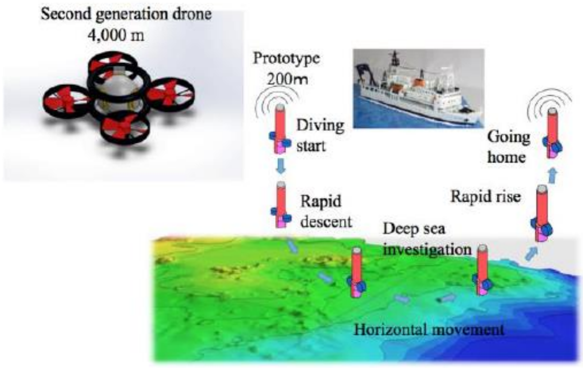

Fig. 9. The drone is working in the deep sea.

V. CONCLUSIONS

The authors have concluded as follows.

1) The spherical ultrasonic motor shows good maneuverability in water.
2) The authors have made the prototype of deep-sea drone and shown the potential of practical use in sea.

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