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Research Article

Development of Small-size Jellyfish Removal ROV and its Evaluation of Removal Motion Performance in Tank

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ABSTRACT

In recent years, increase in the number of jellyfish causes damage in the fishery and tourism industries. Currently, most of the jellyfish removal work is carried out by workers. However, this conventional removal work is required a lot of time and manpower. In this paper, we proposed a method for removal work of jellyfish using an underwater robot. Also, we introduced developed ROV type underwater robot, which is called JENOS (Jellyfish Extermination Nifty-robot for Ocean Sustentation), and its removal motion performance. The ROV was developed in consideration of the attitude control during the removal operation. Because, the attitude, such as surge and pitch, of ROV became unstable when performing jellyfish removal work. To solve this problem, we equipped 8 thrusters to improve attitude stability during the jellyfish removal work. As results, surge acceleration was reduced about 30.0%, and pitch angle velocity was reduced about 25.8%, and the jellyfish sample was chopped within 25 seconds.

1. Introduction

In recent years, the massive increase in the number of jellyfish causes ocean environment damage such as decrease in biodiversity. Also, the number of jellyfish increases across Asia, it damages the fisheries, power generation and tourism industries[1,2]. It is supposed that these causes are overfishing of fishery resources, changes in coastal topography due to global warming, and eutrophication[3]. In Japan, the aurelia, which is small and poisonous jellyfish, damages to human activities such as fisheries and tourism industries. Furthermore, they gather at the water intakes of power plants, and clog the intakes[4,5]. Therefore, jellyfish removal work is carried out to reduce such damage by fishery workers or experts.

Conventionally, jellyfish removal work is used fishing nets. The workers catch jellyfish using fishing nets, and then caught jellyfish is cut up by the electronical tools. However, this method is required a lot of cost such as financial cost, time, and manpower. Furthermore, the number of fishery workers in Japan decreases in recent years by various factors such as change industry[6].

Recently, underwater robotics can be mentioned as a solution to this situation. Because small-size underwater robots can work over a large area for a long time, and low cost compare with divers.

In this paper, we designed and developed a ROV (Remotely Operated Vehicle) for jellyfish removal work, which is called JENOS (Jellyfish Extermination Nifty-robot for Ocean Sustentation) and designed to evaluate jellyfish removal motion performance of ROV in tank.

2. Development of Jellyfish Removal ROV

2.1. *Proposed jellyfish removal work using ROV*

The proposed jellyfish removal work using the ROV was operated on the small size fishing boat. The detail of

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proposed jellyfish removal ROV operation is illustrated in Fig.1.

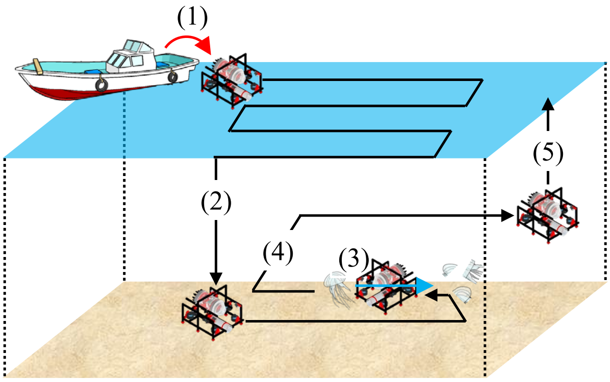

Fig. 1 Overview of the proposed jellyfish removal ROV operation method

The proposed operation in Fig.1, the ROV have 5 steps, which detailed below, to remove jellyfish in the sea area.

(1) The ROV and operator are carried using a boat to the field where is number of jellyfish is increasing. Then, the ROV is dropped to the sea area.
(2) The ROV is controlled by operator on the boat to search jellyfish under water. If a jellyfish is found, the ROV approaches to the jellyfish.
(3) The jellyfish removal device, which is mounted to ROV, sucks the jellyfish with water. Then the jellyfish was cut by the blade of removal device.
(4) The ROV is controlled to search other jellyfish in the same sea area.
(5) When the removal work in the target sea area finished, the ROV is returned on the boat. Then, operator try to same works in the other sea area.

We develop a ROV which can operate these steps in Fig.1.

2.2. *Design concept and specifications of ROV*

The ROV is necessary several condition to operate the proposed jellyfish removal work on the small size boat. The design concept of ROV, which is considered to develop, is described below.

(i) Small size and light weight
(ii) High maintainability
(iii) Wide viewing angle and high recognition rate
(iv) High positional stability

We proposed a ROV operation method, which can be carried out with a few workers compared to conventional method, in the Fig.1. Therefore, the design concept of ROV, which can perform (1) ~ (5), is required. For the design concept (i), size and weight must be designed easy enough to be drop and return on the boat by 2 people.

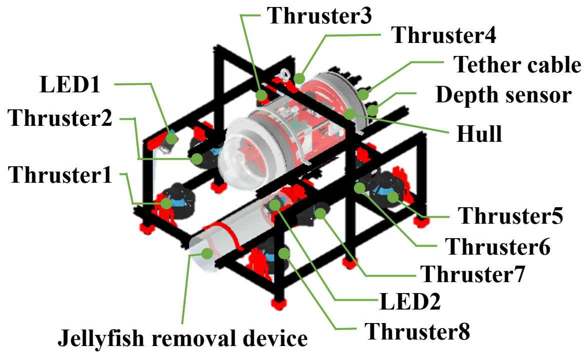

Fig. 2 Overview of designed the ROV for jellyfish removal work

Because the minimum number of people requires to work on a boat is 2 for the safety.

Table 1 Specifications of developed to ROV

Dimensions	0.65 x 0.52 x 0.47 [m] (L x W x H)
Dry weight	17[kg]
Maximum depth	10[m]
Actuator	Thruster x 8, Micro servo motor x 2
Battery	Lithium-ion battery
Sensors	USB camera, IMU, Depth sensor
Umbilical Cable	100[m] length, 7.6 [mm] diameter
Equipment	LED x 2, Jellyfish removal device Voltmeter
Angle of view	Pan110[deg], Tilt120[deg]

The purpose of the design concept (ii) is to ensure that if a problem occurs during the operation, such as a poor connection or dead battery related to the internal system of ROV, it can be recovered and repaired quickly.

Underwater environment is dark and makes it difficult to recognize objects. Therefore, like the design concept (iii), the ROV is necessary to light source and wide viewing angle.

In the Fig.1, we proposed an operation method, which is sucked the jellyfish and cutting them. However, in this way, the posture of the ROV tends to be unstable because of the suction device applies the force to ROV. Therefore, the ROV is necessary to high positional stability for jellyfish removal work in the design concept (iv). The designed ROV, which is considered the design concept (i) ~ (iv), is shown in Fig.2 and the ROV specifications is shown in Table 1. As shown in Fig.2, the ROV includes a hull, which is composed camera dome and acrylic cylinder, thrusters, LEDs and jellyfish removal device.

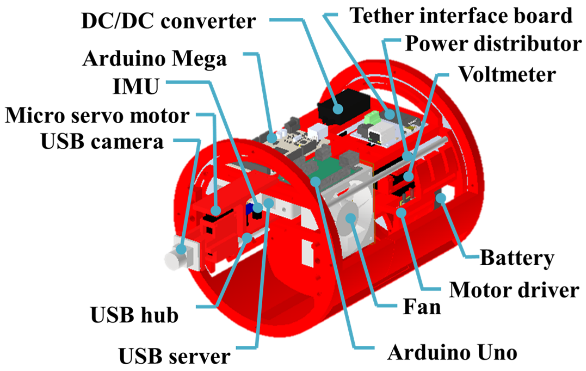

Fig. 3 Inside design of the hull of developed ROV

Each device was equipped using aluminum frames to ROV. The ROV was designed 0.65 x 0.52 x 0.47[m] and 17[kg] because of design concept (i) for the drop and return work. This size and weight were made possible the removal operation using the ROV by 2 grown mans on the boat. The ROV hull inside was designed as a module for design concept (ii). The inside design of hull is shown Fig.3.

As shown in Fig.3, the control units such as Arduino, battery, motor drivers, sensors are placed on hull inside. This is the single module part, which designed to be easily inserted into and removed from the hull, by slide mechanism. The camera system was composed by a camera, 2 LEDs and 2 micro servo motors to satisfy design concept (iii). The camera system could move to pan and tilt angle. Also, the LEDs, which has a maximum brightness of 1,500 lumens, were equipped.

The ROV has low positional stability during jellyfish removal work because the center of rotation of ROV and jellyfish removal device are mounted at a distance as shown in Fig.2. Therefore, the force from jellyfish removal device occurred to surge direction and pitch angle. This force made the ROV posture unstable, and it is made difficult to jellyfish removal work. To satisfy design concept (iv), the ROV was mounted 8 thrusters, which are maximum output of 5.25 [kgf] at 16 [V]. We placed 4 thrusters in the surge and sway directions, and other 4 thrusters are placed in the heave direction as shown in Fig.2 for high positional stability of the ROV.

2.3. *Design of power and communication system*

The power source of the ROV was employed a lithium-ion battery which is 14.8[V], 18[Ah]. The designed power system is shown in Fig.4.

The battery is supplied DC 14.8 [V] to electronic parts as shown in Fig.4. DC 14.8[V] is employed to supply power to fan, voltmeter, LEDs, motor drivers and tether interface board. Also, DC 5[V], which is employed to

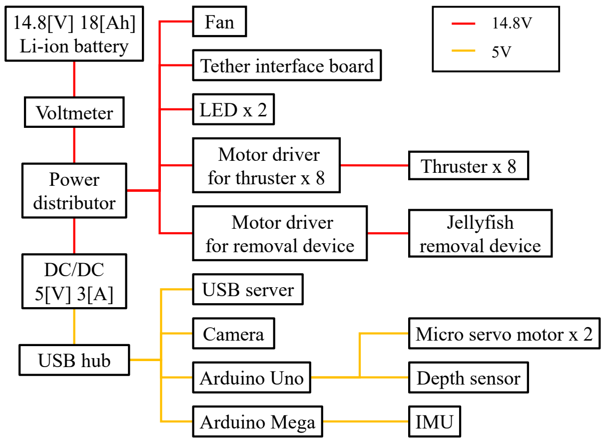

Fig. 4 Overview of ROV power supply system

sensors and processing units, is converted by DC/DC converter, and that is employed to supply power to USB server, camera, Arduino Uno and Mega.

The communication system of ROV is illustrated in Fig.5.

As shown in Fig.4, the ROV communication system is employed various communication formats such as ethernet or USB serial. The computer on the boat is connected to ROV by ethernet cable via tether interface and then the ethernet signal is converted to USB serial by USB server. The USB hub, which connects to Arduino Mega and Uno, is connected to USB server. Arduino Mega controls the thrusters, which include the jellyfish removal device, LEDs and get the IMU data. The PWM signal is employed for the thruster and LED control. The PWM signal, which output to Arduino Mega, has 1100 to 1900 [micro sec.] range. Arduino Uno controls micro servo motors for camera movement and get the depth sensor data.

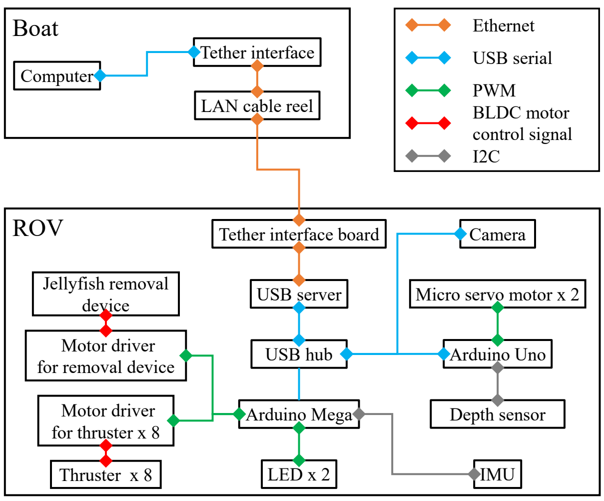

Fig. 5 Overview of ROV communication system

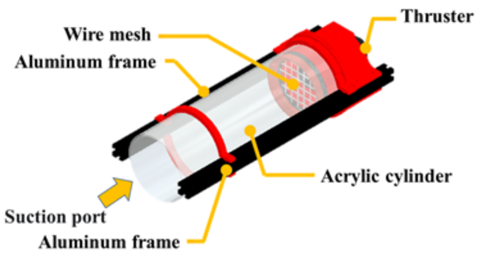

Fig. 6 Overview of jellyfish removal device

Table 2 Specification of jellyfish removal device

Dimensions	0.46 x 0.15 [m] (L x W)
Dry weight	2[kg]
Actuator	Thruster(T200)
Suction port diameter	100[mm]
Wire mesh size	15 x 15[mm]
Thrust	Up to 4.07 [kgf] at 16 [V]

2.4. *Jellyfish removal device*

We propose jellyfish a removal method using suction device, which mounted on ROV, in Fig. 1. The jellyfish removal device, which can be possible the proposed ROV operation method, is illustrated in Fig.6 and the specifications is shown in Table2.

The jellyfish removal device is composed of a thruster, wire mesh, acrylic cylinder, and frames as shown in Fig.5. When the thruster rotates, the jellyfish was sucked in and cut off by the wire mesh and blade of thruster. In the proposed jellyfish removal ROV operation method, we didn't collect cut jellyfish pieces because the pieces are used as food for marine organisms in marine ecosystem.

The wire mesh was made of stainless steel and the mesh size is 15 [mm] x 15 [mm]. It also served to crush jellyfish and to protect hard objects other than jellyfish, such as large rocks and shells, from the thruster.

3. Evaluation experiment of developed ROV

We experimented using developed ROV to evaluate removal motion performance. The stability of removal motion of ROV was evaluated by first experiment, and suction performance of the jellyfish removal device was evaluated by second experiment.

For the motion stability, the jellyfish removal motion of ROV was evaluated with acceleration data and angular velocity data from equipped IMU.

For suction performance of jellyfish removal device, the device was evaluated with the jellyfish sample removal time and the flow velocity.

3.1. *Evaluation of removal motion control*

The removal motion of ROV was performed using jellyfish removal device which mounted on downside of the ROV. Therefore, when was used the jellyfish removal device, the pitch angle rotates as the ROV moves forward. To solve this problem, we stabilized the posture by using other thrusters mounted on the ROV. In this experiment, the thrust of the removal device was set to 1.44 [kgf]. The control results are shown in Fig.7, and the scene of experiment is illustrated in Fig.8.

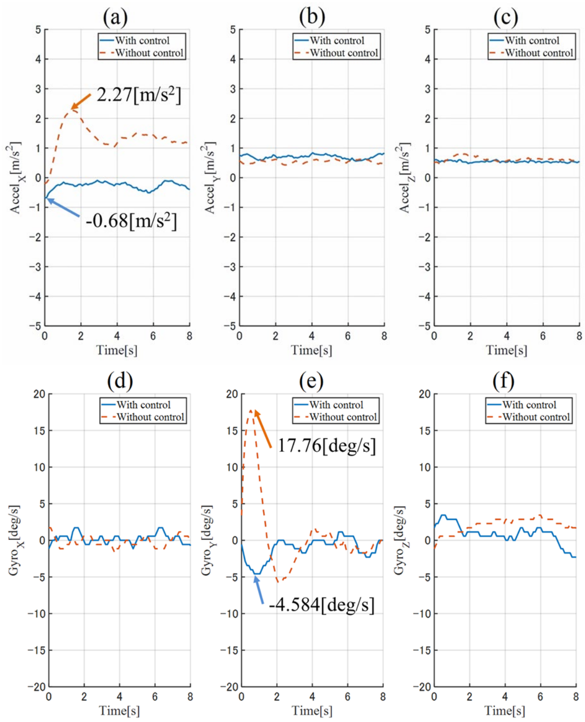

Fig. 7 Experiment results of ROV motion control by IMU

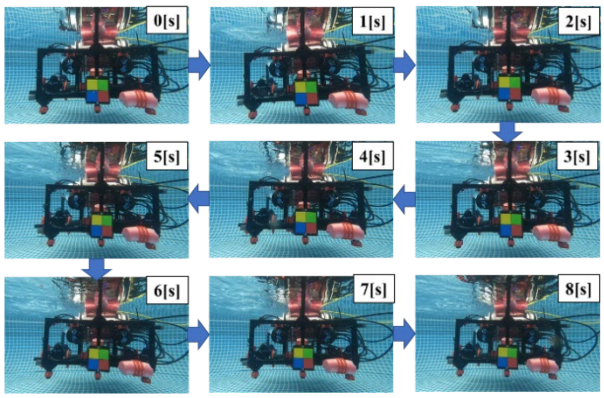

Fig. 8 Scene of the ROV control of jellyfish removal motion

(a) ~ (b) in the Fig.7 represents acceleration of surge, sway, and heave direction. And (d) ~ (f) in the Fig.7 are shown angular velocity of roll, pitch, yaw angle. The dashed lines represent acceleration and angular velocity during removal motion without control of other thrusters, and the solid lines represent acceleration and angular velocity during removal motion with control of other thrusters. Also, each data is measured by IMU which is mounted the ROV.

Fig.7 (a) in the dashed line, the ROV can confirm that the acceleration is applied in the surge direction during removal motion and its maximum acceleration of the surge direction was 2.27[m/s^2]. Fig.7 (a) in the solid line represents the surge acceleration which is reduced by mounted thrusters on ROV. As a control result, the acceleration of surge direction is about 30.0% reduced. Fig.7 (b) and (c) are shown acceleration of sway and heave direction, and there was little acceleration in those direction.

Fig.7 (d) and (f) are shown angular velocity of roll, yaw angle, and there was little angular velocity in those direction. However, Fig.7 (e) in the dashed line is shown high angular velocity and its maximum angular velocity of the pitch angle was 17.76[deg/s]. Fig.7 (e) in the solid line represents the angular velocity which is reduced by mounted thrusters on ROV. As a control result, the angular velocity of pitch angle is about 25.8% reduced.

We can verify in Fig. 8 that the acceleration and angular velocity are highly reduced. In Fig. 8, a marker is attached to the lower center of the ROV, and the movement of the marker was observed during the removal motion. As a result of observation, it was confirmed that the removal motion of ROV is highly stabilized.

3.2. *Evaluation of jellyfish removal device*

We experimented to evaluate the flow velocity of the jellyfish removal device. In this experiment, the 3 types of truncated cone shape jellyfish samples, which composed of water and gelatin, was employed. The detail of 3 types of truncated cone shape jellyfish samples is shown in Table 3.

Table 3 Detail of jellyfish samples

Tape		A	B	C
Used amount of	Water [ml]	200	300	400
	Gelatin [g]	5	10	15
Volume [mm^3]		199843	387733	503702

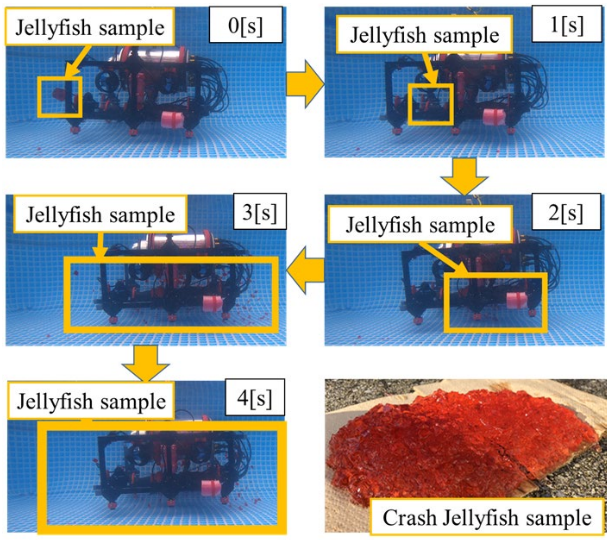

Fig. 9 Scene of jellyfish removal device experiment

Table 4 Experiment result of performance of jellyfish removal device using jellyfish samples

Type	A	B	C
Flow velocity [m/s]	0.60	0.56	0.53
Sample removal time [s]	3.22	9.57	24.75
Number of collected sample pieces	121	157	259
Average volume of collected sample pieces [mm^3]	2443	2300	2504

Each jellyfish sample in Table 3 is made using 200, 300, 400 [ml] of water, 5, 10, 15[g] of gelatin, 1, 2, 3[g] of red food coloring.

In the experiment, the sample was dropped in front of the jellyfish removal device and then sucked to measure the flow velocity. Using an underwater camera, the jellyfish samples were recorded at 120 frames and the flow velocity was measured. The force output by the thruster which was mounted jellyfish removal device was 1.44 [kgf]. The scene of device evaluation is shown in Fig.9, and the experiment result is shown in Table 4.

As shown in Fig.9, each jellyfish sample is chopped by removal device. In Table 4, the measured flow velocity when sucks the samples are 0.60[m/s], 0.56[m/s] and 0.53[m/s]. Also, we collected chopped pieces of jellyfish sample to evaluate jellyfish removal performance by pieces size. As a result, we collected 537 chopped pieces, and those average volume were 2443, 2300 and 2504 [mm^3].

4. Conclusion

In this paper, we designed and developed a ROV for jellyfish removal work, and then the ROV motion control to jellyfish removal and performance of jellyfish removal device were evaluated. The design concept of ROV was shown in (i) ~ (iv), and a ROV was developed that satisfies those concepts.

In the evaluation of removal motion control, maximum acceleration of surge direction was 2.27[m/s^2], and maximum angular velocity of pitch angle was 17.76[deg/s] by the thruster which is mounted jellyfish removal device without other thruster control. By the equipped with control system, the acceleration of surge direction was reduced about 30.0[%], and angular velocity of pitch angle was reduced about 25.8[%].

The removal device was shown enough performance to remove the jellyfish. Especially type C jellyfish sample, which has 503702 [mm^3] volume, was chopped until 2504 [mm^3] volume. This result was about 0.5% of the original volume, therefore it was sufficient to remove jellyfish.

There are many issues to be solved for the operation in the oceans, such as automatic recognition of jellyfish and improvement of attitude control capability such as hovering control of the ROV. In the future, we will solve these problems and try to make practical use of the ROV for small jellyfish removal operations.

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