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journal or publication title	Proceedings of International Conference on Artificial Life & Robotics (ICAROB2022)
page range	785-788
year	2022-01-22
URL	http://hdl.handle.net/10228/00008701

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Abstract

As the fuel cost will rise continuously, the reduction of fuel consumption and CO2 emissions are required more severely in the transportation industry. To achieve more efficient ship transportation, the prevention of marine biofouling is inevitable. Anti-fouling paint is effective to prevent biofouling to the ship hulls like barnacles, however, even the painted hull acquires slime-like biofouling caused by marine alga on its surface easily. In general, the cleaning of the ship hull is carried out during inspection in dockyard once a year or by divers, which are high costs and high risk task. Frequent cleaning during the ship berthing is desirable to keep good fuel efficiency, and if possible, ships can keep good fuel efficiency that contributes the reduction of costs and CO_2 production. As a solution for this issue, we have been introducing underwater robots for ship hull cleaning. In this paper, the motion control system of the robot is described.

Keywords: Under Water Robot, Ship Hull Cleaning, Attitude Control

1. Introduction

Global warming caused by greenhouse gases is getting worse, and in recent years there has been a growing demand for reduction of greenhouse effects in various fields. In addition to reducing CO_2 emissions, there is an increasing demand for reductions in fuel consumption due to soaring fuel prices.

In order to satisfy these demands, it is also necessary to make the ship transportation efficient and reduce the ship resistance.

The hull of the ship is always in the sea, and various marine organisms adhere to it for long time. The adhesion of living organisms increases ship resistance and affects the fuel efficiency of ships. It is reported that the fuel efficiency of organisms attached to the hull of a ship deteriorates by about 20% in the first year, and when left uncleaned, it deteriorates by up to about 50% in worst cases [1]. Antifouling paint is effective in preventing the adhesion of organisms such as barnacles, but slime-like organisms due to algae adhere to the surface of the painted hull. In addition, the effect of such paints diminishes over time, so it is necessary to reapply them regularly.

Usually, the method of cleaning the hull of the ship is to lift the ship on land like a dockyard, or to clean it by a diver.

Since docking a ship to the special facility like the dockyard is a large-scale work, it is generally performed about once a year, where cleaning and inspection are performed. However, in order to maintain and improve efficient fuel consumption, it is desirable to clean frequently even while moored. The underwater cleaning operation in the ports by divers is dangerous and the cleaning cost is high.

To solve these problems, we have been developing the robot that can regularly clean the hull of ship in water. This paper describes the motion control of the ship hull cleaning robot.

2. Ship Hull Cleaning Robot

2.1. *Features of the robot*

We have developed ship hull cleaning robots [1]-[3], and the latest robot is shown in Fig.1. The robot has a length of 0.8 [m], a height of 0.4 [m], a width of 0.3 [m], and a weight of about 30 [kg]. The robot has two pressure-resistant cylinders arranged on both sides of the brush unit in the middle. These are arranged so that every equipment is fit inside the metal frame including 6 thrusters. The robot is remotely operated vehicle (ROV) and designed to be the center of gravity and buoyancy as close as possible in order to adjust the posture of robot to the target ship hull angle, and the maximum operation depth is 30 [m]. The main power cable of the robot is AC200 [V] and data is transmitted using PLC (Power Line Communication).

2.2. *System architecture*

The robot system architecture is shown in Fig. 2. PLC is used for communication between the robot and the remote computer for control. The conventional PLC accept 200 [m] length cable and communicate at 200 [Mbps] that is enough speed to transmit two video camera images in the front and rear cylinders of the robot to the remote computer at the speed of 30 [fps].

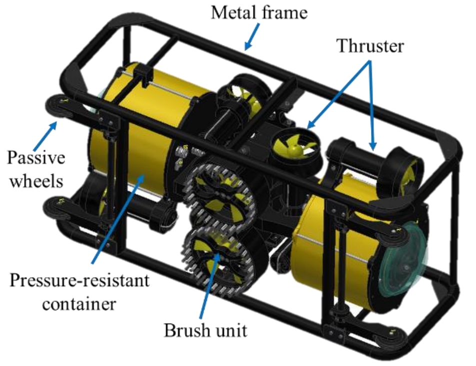

Fig. 1 The ship hull cleaning robot (4th version)

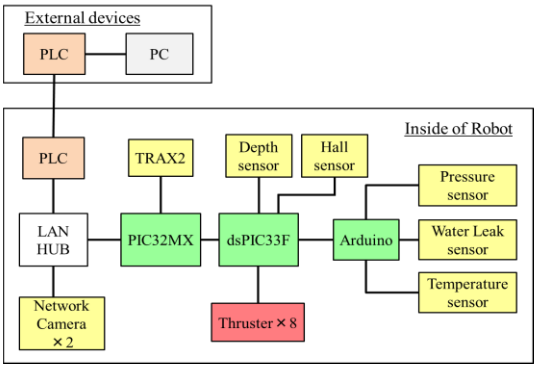

Fig. 2 System architecture

The pressure-resistant cylinder in the front is mainly composed of power supply circuits such as AC/DCs and DC/DCs. The rear cylinder of the robot consists of sensors and circuits for communication and control. TRAX2 is used as AHRS (Attitude and Heading Reference System) for attitude detection and control of the robot. Magnets are mounted on the front and rear passive wheels, and the hall sensor inside the robot determines whether the passive wheels in the brush side are touched to the hull of the ship. In addition, there is a temperature sensor, barometric pressure sensor, and leak detection sensor inside the cylinders for monitoring whether there is any abnormality inside the robot.

Two MPUs, PIC32MX and dsPIC33F, are used for the communication and control boards. The PIC32MX is mainly used for communication with the ground PC, acquisition of sensor values from the TRAX2, and determination of control and operation quantities. The dsPIC33F mainly acquires other sensor values and generates PWM for each thruster. In addition, data is exchanged between the two by serial communication.

Each of the front and rear cylinders is equipped with a network camera.

3. Kinematics

Figure 3 shows the arrangement and positive thrust direction of six thrusters. The two thrusters (1) and (6) are attached in parallel to the X-axis mainly used for Surge and Yaw motion control. The two thrusters (2) and (5) are parallel to the Z-axis for Heave and Pitch motion control. The remain two thrusters (3) and (4) are installed parallel to the Y-axis for Sway and Roll motion control.

The thrust in each mode of motion, Surge direction F^S, Sway direction F^W, and Heave direction F^H, and the moments in Roll direction N^R, Pitch direction N^P, and Yaw direction N^Y by these thrusters can be expressed by the following equation (1).

$$F_T = \begin{bmatrix} F^S \\ F^W \\ F^H \\ N^R \\ N^P \\ N^Y \end{bmatrix} = \begin{bmatrix} T_1 - T_6 \\ -T_3 - T_4 \\ -T_2 + T_5 \\ d_{3Z}T_3 - d_{4Z}T_4 \\ -d_{1Z}T_1 - d_{6Z}T_6 + d_{2X}T_2 + d_{5X}T_5 \\ d_{1Y}T_1 + d_{6Y}T_6 \end{bmatrix} \quad (1)$$

The main symbols used in this paper are shown below.

F^S, F^W, F^H : Total translational force due to thrusters in the Surge, Sway, and Heave directions [N]

N^R, N^P, N^Y : Total moment due to thrusters in Roll, Pitch, and Yaw directions [Nm]

$T_1, T_2, T_3, T_4, T_5, T_6$: Thrust of each thruster [N]

d_{1Z}, d_{6Z} : Distance from the center of gravity to thrusters 1 and 2 in the Z-axis direction [m]

d_{2X}, d_{5X} : Distance from the center of gravity to thrusters 2 and 3 in the X-axis direction [m]

d_{3Z}, d_{5Z} : Distance from the center of gravity to the thrusters 3 and 4 in the Z-axis direction [m]

d_{1Y}, d_{6Y} : Distance from the center of gravity to thrusters 2 and 5 in the Y-axis direction [m]s

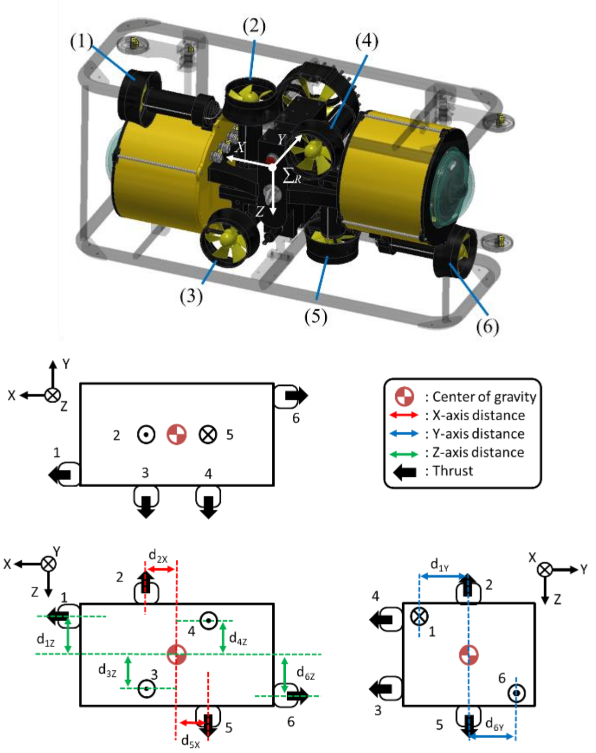

Fig. 3 Arrangement of thrusters with corresponding thrust directions

4. Cleaning Experiments

The heave, roll and pitch data in experimental results are shown in Figs. 4 and 5. During the cleaning work, the operator gives the target depth and target thrust to the robot, and the robot operates by PD control. When the robot cleans the hull of the ship, Heave and Pitch are the control targets.

In this experiment, a thrust force of 20 N is applied in the Surge direction of the robot, and the target depth is changed to 0.6 [m] and 0.9 [m]. From the results in Fig. 4, an overshoot of 0.5 [m] at the maximum appears for each target depth, and the oscillational motion happened around the target value. This result is due to insufficient design of the robot control system. In addition, it is considered that such an operation was performed because the force generated by the brush unit during cleaning and the motion characteristics in the Pitch direction were not taken into consideration.

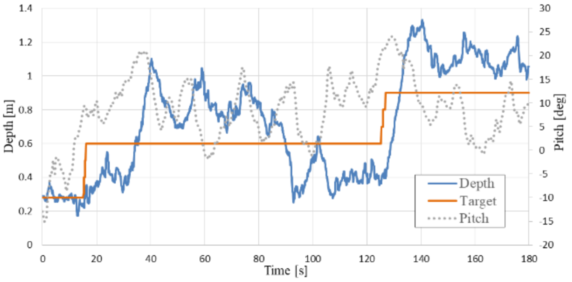

Fig. 4 Results of the experiment (Depth, Pitch)

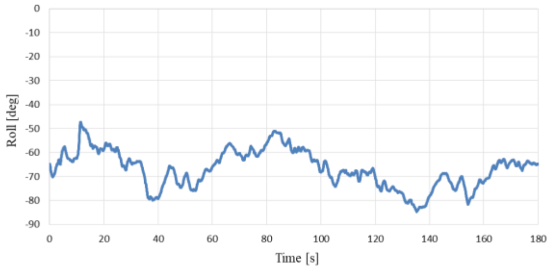

Fig. 5 Results of the experiment (Roll)

Figure 5 shows the attitude change in the direction of the robot Roll. It can be seen that the Roll angle of the robot changes according to the shape of the target hull.

5. Conclusions

In this paper, we have described the new ship hull cleaning robot and the ship hull cleaning experiment using the ship. Experiments have confirmed that the robot can clean and move along the shape of the target hull while changing the depth with respect to the target.

Therefore, it is necessary to design a more stable control system by considering the interaction between thrusters and coupling effects of motion control modes.

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Acknowledgement

This research is supported by Grant-in-Aid for Scientific Research(B) 18H01643.

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