Motion Compensator for Acoustic Device Mounted on Autonomous Surface Vehicle

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***Abstract*—In recent days, the simultaneous operation of several AUVs is desired to realize widespread exploration in a navigation. As a method to realize the simultaneous operation, introduction the repeater vehicle called ASV (Autonomous Surface Vehicle) is proposed. The task of the ASV is to chase an AUV and to communicate with a support vessel. So, one ASV is needed for one AUV but several ASVs are monitored by one support vessel. The size of the ASV is similar to the AUV and is significantly smaller than the support vessel, so the seakeeping qualities are lower than the support vessel. Larger ship motion is expected than the support vessel and causes communication trouble. In this report, the new active motion compensator and the model experiment with this motion compensator is reported.**

Keywords—Autonomous Surface Vehicle; ASV; Motion Compensator; Model Experiment; Wave

I. Introduction

In recent years, the seafloor exploration utilizing AUVs have activated. Generally, Cruising type AUV is operated one-on-one with a support vessel. The support vessel chases the AUV to communicate information, so only one AUV can be operated in an investigating navigation. If several AUVs can be operated in parallel, it contributes to the widespread and smooth exploration.[1]

For the simultaneous operation of several AUVs, the repeater vehicle called ASV (Autonomous Surface Vehicle) is introduced. An AUV can communicate with an ASV, ASV can communicate with a support vessel. The support vessel can communicate several ASVs. Introduction of simultaneous operation of several AUVs with ASVs makes it possible to realize widespread exploration.

II. Objectives

The difference between monitoring by a support vessel and by an ASV is the size of the vessel (vehicle). The size of the ASV is similar to the AUV and is significantly smaller than the support vessel, so the seakeeping qualities are lower than the support vessel. The large ship motion makes trouble about the communication utilizing acoustic device between the ASV to the AUV. To solve the problem, the active motion compensator for the acoustic device is developed. The concept of the compensator is shown in Fig.1. In Fig.1 the cone represents the area of acoustic communication.

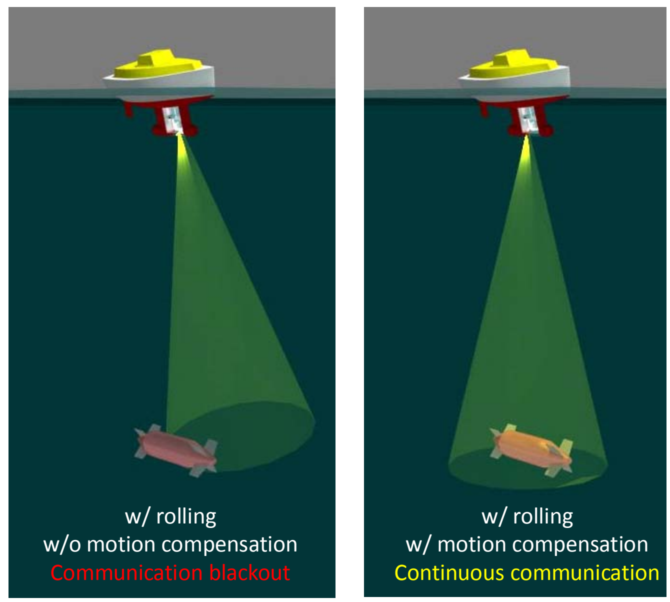

Fig. 1. The concept of the motion compensator for the acoustic device

The objective of this research is to compensate the motion of the acoustic device in waves to prevent the disconnection of communication between the ASV and the AUV.

III. Method of Experiments

The model experiments are conducted at the towing tank at Yokohama National University. To evaluate the effect of the motion compensator, the results of w/o control and w/ control are compared.

A. Experimental model

The scale model for the tank experiment is introduced. The scale ratio of the model is 1/6. Thrusters, a rudder, motors are mounted for the free running experiments. Sensors for vertical acceleration, roll angle and pitch angle are mounted to measure ship motions. The principal dimensions of the ASV are displayed in Table 1.

TABLE I. PRINCIPAL DIMENSIONS OF THE ASV

	Actual	Model
Scale	1	1/6
L(O.A.) [m]	6.00	1.010
L(Lpp) [m]	5.42	0.904
B(MLD) [m]	2.57	0.428
D(MLD) [m]	1.46	0.243
d(Design.) [m]	0.484	0.0807
Displacement[kg]	2400+	12.22
GM[m]	-	0.0677
Κyy/L (gyradius of Pitch)	-	0.263
Κzz/L (gyradius of Yaw)	-	0.256
Κxx/B (gyradius of Roll)	-	0.348

B. Actuators for motion compensation

The motion compensator is composed of three actuators. The actuators move the acoustic device in the vertical direction and rotates in the rolling and pitching direction. Each actuator corresponds to each motion as shown in Fig.2. Sensors for vertical acceleration, roll angle, pitch angle and roll rate are installed at the position of the acoustic device to evaluate the effect of this compensator. The part for acoustic device is called "Stabilizer for Acoustic Device".

As shown in Fig. 3, the actuators for roll and pitch are installed inside the keel. The space inside the keel is filled with water because the actual acoustic device is used under (in) water. Only the actuator for heave is installed inside the ship hull.

C. Control system for tank experiment

The control system used in the model experiment is shown in Fig.3. The data for control are rolling and pitching angle and vertical acceleration of the vessel. The PD feedback control is introduced for compensation of the acoustic device. The control method is introduced for each motion (one control for one motion). The sensors on the ship are used for input of the control program and the sensors on the part of acoustic device are used for evaluation of motion compensation.

The experimental arrangement in the towing tank is shown in Fig.4. The data of ship motion are converted from analog to digital and sent from the model to PC (controller) for control. The controller calculates how to move the actuators and send signal to the actuators via wireless communication (utilizing general wireless LAN).

D. Experimental conditions

Two types of experiments are conducted, one is experiment in waves and another is an experiment by forced oscillation.

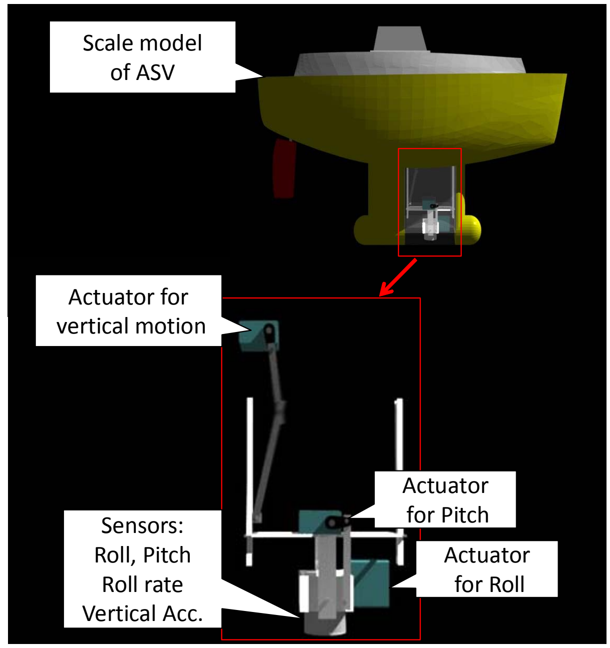

Fig. 2. Actuators for motion compensation

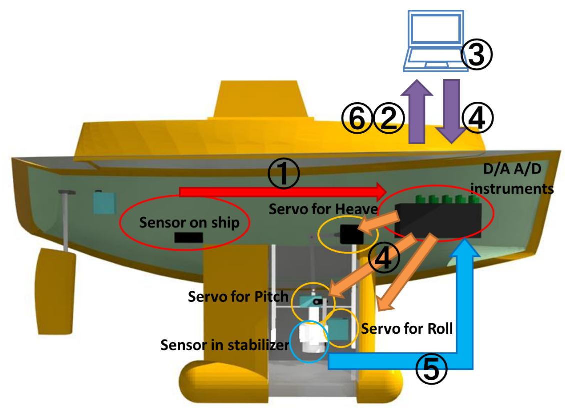

Fig. 3. The control system of motion compensator

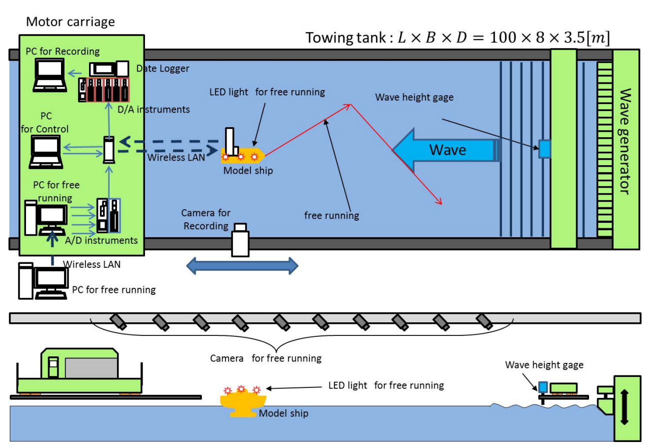

Fig. 4. The experimental arrangement in the towing tank

Fig. 5. Ultra-small-buoy for wave measurement developed by Yokohama National University

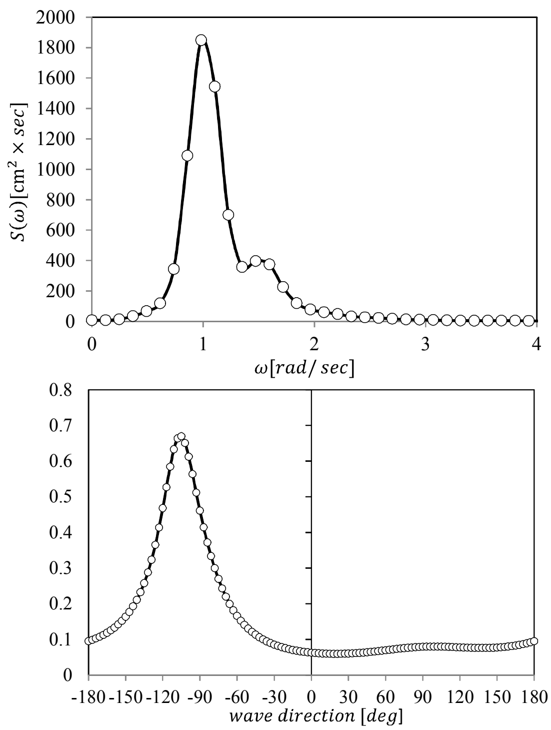

Fig. 6. Example of power spectrum and directional distribution of wave on pacific ocean near Japan (0 deg: North)

The period of forced oscillation is longer than the period of the waves.

To determine wave periods and heights for the tank experiment, wave observation on pacific ocean before the tank experiment is referred. In the wave observation, ultra-small-buoy is utilized as shown in Fig. 5. To calculate the wave power spectrum, vertical acceleration, roll angle, pitch angle and heading angle are used.[6] [7] The power spectrum shown in Fig.6 shows the wave power spectrum measured by small buoy. From the power spectrum, 4.9s as zero up-crossing period and 2.4m as significant wave height is obtained. The desired value of wave period and height in the towing tank are 2.0s in period and 0.4m in height.

TABLE II. WAVE CONDITIONS

χ=180 [deg], V_m=0.5m/s (V_s=2.4kts)

	Exp. value/(Actual value)			
Period [s]	2.00 (4.90)	2.00 (4.90)	3.00 (7.35)	3.00 (7.35)
λ/L	6.2	6.2	14.1	14.1
Height [m]	0.088 (0.53)	0.107 (0.64)	0.063 (0.38)	0.084 (0.50)

χ=0 [deg], V_m=0.5m/s (V_s=2.4kts)

	Exp. value/(Actual value)			
Period [s]	0.80 (1.96)	0.88 (2.16)	2.00 (4.90)	2.00 (4.90)
λ/L	1.0	1.2	6.2	6.2
Height [m]	0.022 (0.13)	0.034 (0.20)	0.048 (0.29)	0.088 (0.53)

χ=90, V_m=0m/s

	Exp. Value (Actual value)
Period [s]	2.00 (4.90)
λ/L	6.2
Height [m]	0.069 (0.41)
χ [deg]	90

TABLE III. CONDITIONS OF FORCED OSCILLATION

	Period [s] Exp./(Act.)	1.50 (3.67)	4.00 (9.80)	8.00 (19.60)	12.00 (29.39)
Mode	Heave	✓	–	–	–
	Roll	–	✓	✓	✓
	Pitch	–	–	✓	–

But it's difficult to realize the wave height in the towing tank according to the limitation of the wave generator. The conditions of regular waves for tank experiments are determined as shown in Table 2.

Another experiment is forced oscillation. To check the control system, the periods of forced oscillation are longer than the period of waves and determined as shown in Table 3.

IV. RESULTS FROM THE EXPERIMENTS

The model can run by itself by mounted motors, rudder propellers. The model running in waves is shown in Fig. 7.

An example of the time history of a regular wave experiment is shown in Fig. 8. And Fig. 9. The blue line represents the motion of the ASV. The red line represents the motion of "Stabilizer for Acoustic Device". As shown in Fig. 8

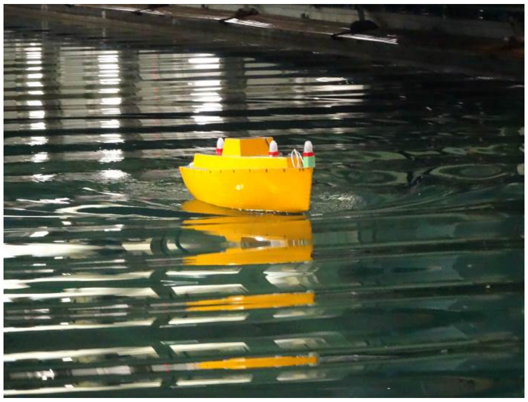

Fig. 7. The model ship of ASV running in wave by the auto-pilot system in the tank utilizing electric motors and rudder

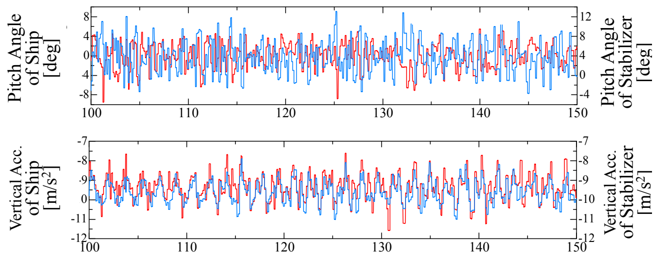

Fig. 8. Time history in regular wave, head sea, wave period: 2.0s, wave height: 0.09m

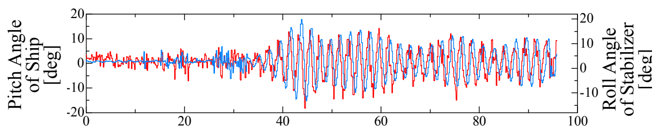

Fig. 9. Time history in regular wave, beam sea, wave period: 2.0s, wave height: 0.07m

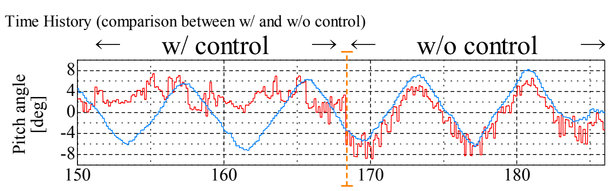

Fig. 10. Time history in forced oscilation

and Fig. 9, it's difficult to find the effective results in all motions from the experiment in waves. The control could not catch up the motion of the vessel. To shorten the time for control, extra functions in the control program are cut. But this time delay problem is not solved. It takes 0.55s for a cycle in the control program. When the time for a cycle was checked before the experiment, it took about 0.03s for a cycle. Several devices for signal input and output were added for the experiment, adding devices caused large time delay.

From the experiment by forced oscillation, the effective results are found in rolling and pitching motion because the periods is enough long for the control program to catch up the motion. An example of a time history of forced oscillation is shown in Fig.10. Fig.10 is the time history of pitching angle of the model ship (blue line) and the acoustic device (red line). As can be seen in the Fig.10, pitching angle of the acoustic device is suppressed into 52%.

V. Conclusions

Development of the active motion compensator for the acoustic device is important to realize the simultaneous operation of several AUVs. To verify the motion compensator, tank experiments utilizing a scale model of the ASV.

Rolling and pitching angle could be suppressed by the introduced control method in comparatively long period. In the case of the period of 8s, the reduction rate of pitching of the part of acoustic device is 48%.

In a comparatively short period (experiments in waves), effective result was not found. The time delay of data communication from the model to the controller and from the controller to the model caused the problem. So the problem is expected to be solved by introducing the high speed communication system.

Acknowledgment

The part of wave observation was supported by the Japan Science and Technology Agency (JST). The authors would like to thank JST, and also thank ship crew of research vessel "Taka-maru", the member of National Research Institute of Fisheries Engineering and FURUNO ELECTRIC as participants of wave observation and the participants of tank experiments.

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