Image Collection Experiments of a Handy AUV for Offshore Structure Inspection

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Abstract

In recent years, in Japan, with the decline in the working population, there has been a noticeable shortage of labor at construction sites and offshore operations. On the other hand, with the aim of realizing a GX society, it is expected that offshore wind power generation platforms will rapidly increase and be deployed offshore. Since it is not easy to access offshore platforms, it is necessary to automate equipment inspection work, and it is expected that the use of AUVs will be particularly desirable for underwater inspection work. The most basic inspection work is assumed to be to collect images of underwater structures. Therefore, in this study, we created an AUV and conducted an image collection experiment using a pier owned by our university as an example to confirm its functionality.

Keywords: Offshore wind firm inspection, AUV, Underwater image

1. Introduction

In recent years, the worldwide development of wind-power generation has been expanding and the development of offshore wind power is booming in some areas because the construction site of onshore wind power is saturated. For example, in Europe, due to saturation of onshore wind power sites, it is expected that the installation capacity of offshore wind firms will continue to increase, under the condition that the European Union aims at reaching about 100 GW of offshore wind capacity by 2030 [1].

In Japan, the goal of either reducing greenhouse gas emissions to virtually zero or becoming carbon neutral by 2050 was set by the Cabinet recently. In 2020, the government released its “Green Growth Strategy for Carbon Neutrality by 2050”, which sets 14 action plants that Japanese industries should start making efforts to realize the net zero society. Under this strategy, wind power is considered very important and set as one of the 14 action plans, with the goal of introducing 10 GW of offshore wind power by 2030 and 30–45 GW by 2040. Since Japan’s topography has few open plains, to achieve this ambitious goal, accelerated development of offshore wind firm is required [2] and many offshore platforms will be installed off the coast of Japanese islands.

These offshore wind power platforms will be located far from the shore and accessing many platforms will not be easy. Generally, when maintaining offshore wind power facilities, some specialized crews have to be transferred to the platform using a CTV (Crew Transfer Vessel). If one platform can generate 10MW power, then around 4000 platforms must be installed to achieve the 40GW goal. In that case, it is not hard to imagine that maintenance costs will become huge because an operator must hire CTVs which goes around those platforms. So our concept is such that each platform should be equipped with a unmanned inspection robotic system which performs base inspection menus like taking images from underwater structures to up water windmill structures.

Image collection is one of the basic inspection menus for offshore structures such as harbor structures [3]. Underwater structures are damaged by long-term use and may be corroded by salty sea water. So, inspection process should be performed to check the safety of the structures. The regular safety inspection is very important to prevent collapse accidents. The conventional inspection of harbor structures used to be carried out by professional divers. However, recently, the aging of professional divers and the lack of successors have become a very critical issue in Japan. Also, while port structure is shallower than approximately 20m, structure of an offshore wind platform like a semi-sub column is likely to be deeper than 30m, which makes divers limit their activities in both time and space.

ROVs are widely used for offshore platform inspection [4], where it is assumed that an operator will operate the system by monitoring underwater camera images. In out concept, the inspection procedure must be performed unmanned, so even if the vehicle has a tether cable, the system should be developed as autonomous.

2. AUV System Development

2.1. *System architecture*

An external view of the developed AUV is shown in Fig. 1. It has two pressure-tight vessels, one for the control system and the other for the battery. A total of 6 thrusters are installed, 2 each in the Surge, Sway, and Heave directions. The camera to capture images of the structure is installed inside the acrylic window in front of the upper hull and has a tilt mechanism. It is equipped with sonar to detect obstacles in front and to the sides. A DVL is attached to its bottom to measure altitude above the ocean floor and speed over the ground. The battery is stored in the lower hull, and buoyancy material is placed above to improve self-stability in roll and pitch. This AUV is a prototype for developing various control programs through experiments at sea, and was designed to have an air weight of approximately 120N to make it easier to handle on land. The dimensions of the AUV is shown in Fig. 2.

The architecture of the control system is shown in Fig. 3. This AUV is equipped with two microcomputers. One computer was designed to mainly control input and output of sensors and actuators, and the other computer was designed to control trajectory generation, control mode switching, and image acquisition. It has both wireless LAN and wired LAN, and when a tether cable is attached, it can be used so that it can be connected to a USV or land-based computer and operated in ROV mode. When surfacing and GNSS is available, it navigates using GNSS coordinates, and when it starts diving, it uses dead reckoning from the GNSS coordinates just before diving.

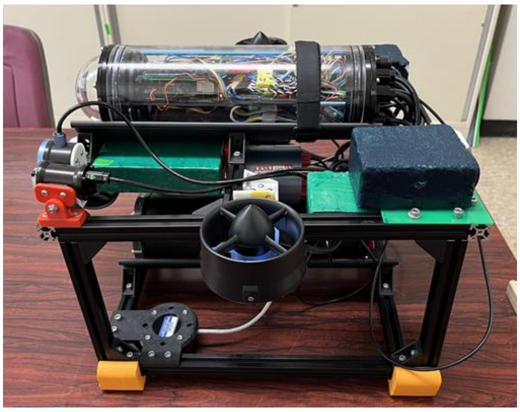

Fig. 1. External view of the AUV

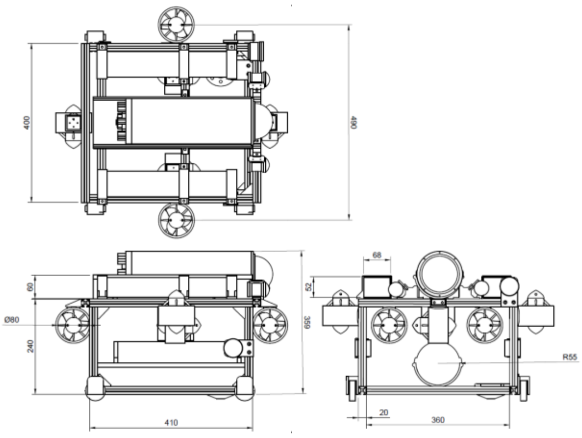

Fig. 2. Dimension of the AUV

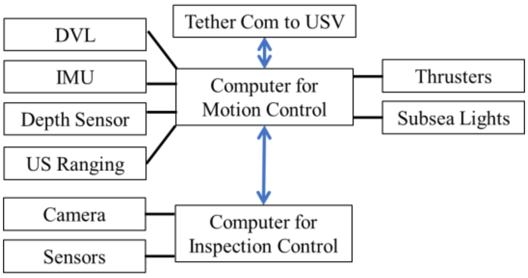

Fig. 3. Control system architecture

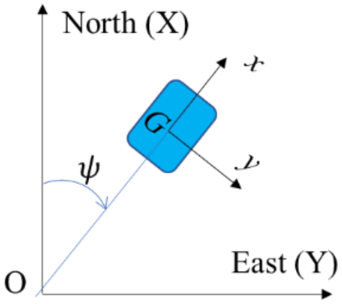

Fig. 4. The coordinate system for horizontal motion

2.2. *Control algorithm*

To implement the control algorithm, we assumed that the motion in the horizontal plane and the vertical motion can be separated because when the velocity is small, the motion in the heave direction has little effect on the motion in the horizontal direction. The coordinate system is set as shown in Fig.4. The coordinate system is a space-fixed coordinate system (O-XY) based on latitude and longitude, and a vehicle-fixed coordinate system (G-xy). G is the vehicle center of gravity. The longitudinal direction of the vehicle is the x-axis and the north is the x-axis. Let the angle formed by the X-axis and the x-axis be the azimuth angle ψ. ψ is positive when clockwise from the north. Space fixed Z axis and vehicle fixed z axis is set as vertically downward to form the right-handed system.

The AUV's equation of motion includes a second-order fluid force term and is nonlinear, but since the speed here is slow, the fluid force is linearized by a representative speed, and the linearly approximated equation of motion is used as the dynamics model. Based on the linearly approximated dynamics model, an optimal control system of 1-type servo was designed and implemented. Here, the system matrix depends on the coordinate transformation matrix which consists of ψ. Since the coordinate transformation matrix changes according to the motion of the vehicle, it is controlled by solving the LQR problem for each step while updating the system matrix at each control step[5], [6].

2.3. *Sea experiment result*

To verify all functions we designed and implemented, we conducted a sea trial experiment at Tatsugo fishing port in Amami Oshima Island. The experiment site is shown in Fig.5. We set a trajectory along the quay of Tatsugo fishing port as shown in the blue line in Fig.5, and conducted an experiment in which we controlled the depth and azimuth while following this trajectory. The results of this experiment are shown from Figs.6 to Fig.9. The following control modes as shown in Table 1 were set for the trajectory tracking control, and the control mode was changed when the error from the control target value became less than the allowable value as shown in the column of the transition condition.

Table 1. Control modes set for the experiment.

Mode	Target	Transition condition
0	Azimuth ψ= 150 deg Depth = 0.5 m (X,Y)=(7.5cos ψ, 7.5sin ψ)	Error of (X,Y)<=1.0m Depth<=0.1m Then go to mode1
1	Azimuth ψ= 150 deg Depth = 0.5 m (X,Y)=(15cos ψ, 15sin ψ)	Error of (X,Y)<=1.0m Depth<=0.1m Then go to mode2
2	Azimuth ψ= -30 deg Depth = 0.0 m (X,Y)=(15cos ψ, 15sin ψ)	Error of (X,Y)<=1.0m Azimuth<=10 deg Then go to mode3
3	Azimuth ψ= -30 deg Depth = 0.5 m (X,Y)=(7.5cos ψ, 7.5sin ψ)	Error of (X,Y)<=1.0m Depth<=0.1m Then go to mode4
4	Azimuth ψ= -30 deg Depth = 0.5 m (X,Y)=(0,0)	Error of (X,Y)<=1.0m Depth<=0.1m Then go to mode5
5	Termination	Stop all thrusters

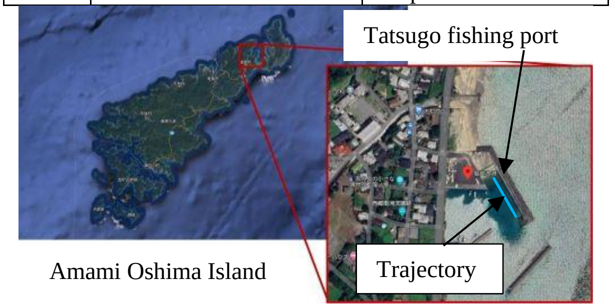

Fig.5. AUV sea experiment site

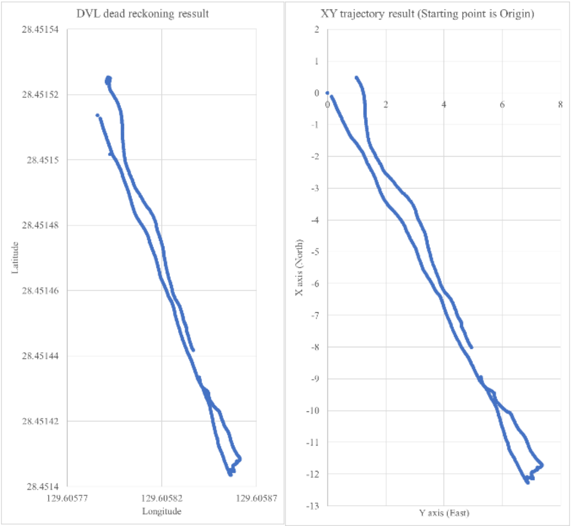

Fig.6. DVL dead reckoning coordinate result

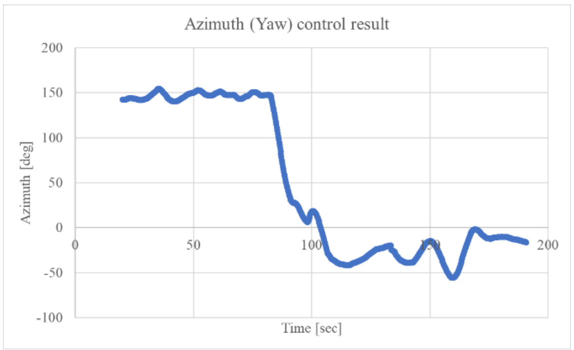

Fig.7. Azimuth angle control result

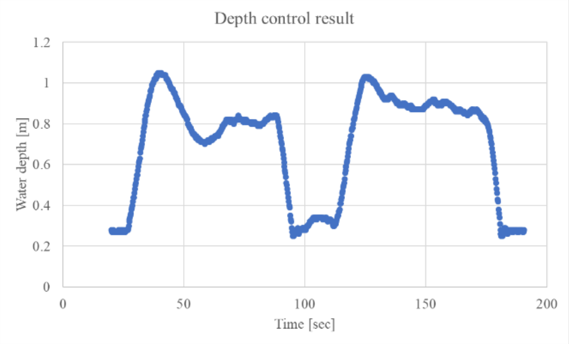

Fig.8. Depth control result (The depth sensor is attached in the middle of the hull cylinder and the initial depth when the AUV is floating is around 0.25m)

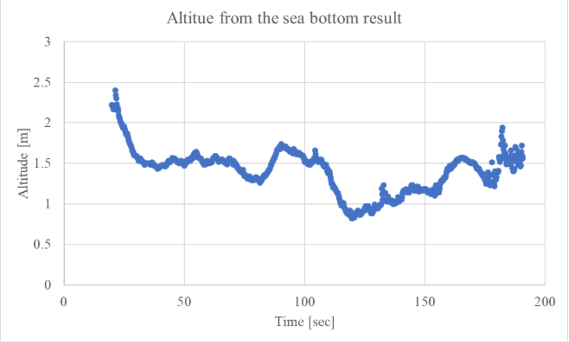

Fig.9. Altitude from the sea bottom

Fig.10 Concrete image captured by the AUV

As shown in those Figures above, despite model errors, all functions of the AUV operated smoothly, and the control mission set as shown in Table 1 was successful. Fig.10 shows an example of captured images of the harbor concrete structure. Because the sea was highly transparent, we were able to obtain relatively clear images. We plan to conduct further research and improve AUV functionality.

3. Conclusion

In this research, we developed an AUV platform and conducted trajectory tracking and image acquisition experiments with the goal of unmanned inspection of offshore wind power generation platforms. It was confirmed that trajectory tracking, azimuth, and depth control all functioned smoothly, and image acquisition surveys could be carried out by setting a trajectory.

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