Design, Implementation, and Experiment of an Underwater Robot for Effective Inspection of Underwater Structures

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Abstract. This paper describes development of a specialized underwater robot for effective inspection of underwater structures. Among various inspection methods of underwater structures, using underwater robots becomes popular. Unfortunately, most underwater robots are not specialized for the inspection purpose. The inspection using traditional method is more inefficient and more inconvenient than the inspection by divers. To overcome this problem, functions to be specialized in the underwater inspection is conceived and these functions are implemented in the developed robot. The type of the developed underwater robot is ROV which is possible to communicate large amount of data in real-time and to supply power efficiently. Moreover, the performance of visual sensor is improved, because most inspection methods rely on visual information. Operational algorithms of the robot developed for stable and convenient operations. The performance of the developed robot is verified in a tank.

Keywords: underwater, structure, inspection, ROV, camcorder, assistance, operation.

1 Introduction

Many underwater structures have been damaged by long term usage. Underwater structures in the ocean are more severely damaged by salt water. These damaged structures may cause a disaster induced from a collapse. To prevent these accidents in advance, the inspection is important to confirm the state of the structures.

The general inspection of underwater structures is a visual inspection by divers. However, this method is not suitable for long time working, and the divers could be exposed to hazardous situations. An inspection using underwater robots can be an alternative. The underwater robots are applied in a various field of working underwater, including wreckage or munitions recovery, underwater sampling, maintenance and construction of underwater structure, surveying and inspection of underwater, and mining to name a few[1, 2]. For this purpose, this paper proposes a specialized underwater robot for inspection task in the underwater environment. The developed underwater robot is a ROV type with visual sensors which can provide high quality performance in the underwater environment.

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The type of ROV is suitable for underwater inspection robot. First, the size of the robot can be minimized because it does not need battery and the main processor also can be separated from the robot. The minimized size of the robot helps to perform the inspection tasks efficiently. Second, it can perform long time operation in underwater environment. Last, it can provide a stable telecommunication for real time visual inspection by using a tether. In fact, the tether might be a major drawback of ROV. The tether might disturb the operation of the robot or be tangled when the robot is operated within a complex structure. For these cases, an expert is needed to operate the ROV. Despite of these drawbacks of ROV, it has several advantages to perform underwater inspection as aforementioned. For this reason, we developed the inspection robot as ROV type to be specialized in the underwater inspection.

The developed robot is equipped with a camcorder for the visual inspection. Traditional underwater inspection robots used underwater cams. In the developed system, the camcorder replaces traditional underwater cam for improvement of inspection performance. In the case of using camcorder, HD image can be obtained in underwater. Moreover, robot is able to use function of camcorder that is auto focusing, zoom in, zoom out and, image stabilization. Using the camcorder as a visual sensor, the developed robot can perform more effective inspection tasks.

The remainder of this paper is organized as follows. Section 2 describes design for specialized underwater inspection and implement of design. Section 3 shows performance of robot to require function of underwater inspection, and conclusion and future directions follow in Section 4.

2 Design and Implementation

2.1 Design of Conception

Figure 1 shows design and main frame of the developed underwater inspection robot. The robot should be easily controlled to maintain the stable pose of the robot and to provide stable images of the inspected structures. For this purpose, the main frame of the robot is designed to be appropriate for the stable control of the robot pose. By arranging a buoyancy material at the top of the main frame, the center of buoyancy could be located above the center of gravity. This structure is possible to maintain stable pose in term of kinematics. And if necessary, it is possible to control posture by thrusts. Other components of the robot including main pressure vessel are arranged at the bottom of the main frame.

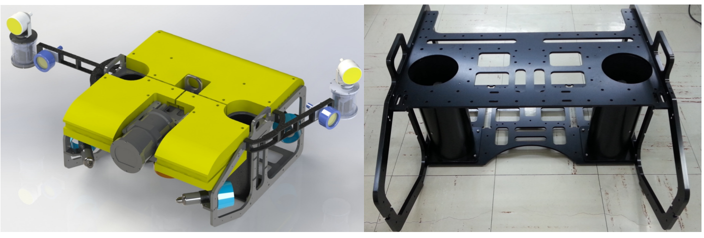

Fig. 1. 3D cad design of robot (right) and Main robot Frame (left)

Figure 2 describes the configuration of thrusters and the corresponding DOF (Degree Of Freedom) of the robot. The thrusters are arranged to restrict the pitching motion of the robot which is not necessary for the inspection tasks. The robot can successfully move with 3 translational motions and 2 rotational motions without the pitching motion using the arranged 6 thrusters [3-6].

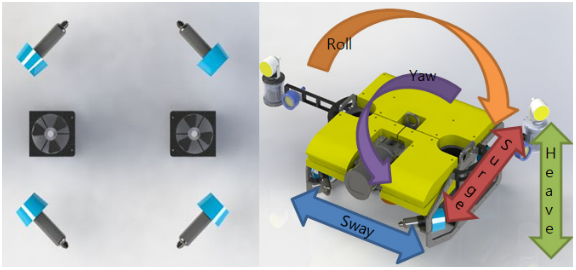

Fig. 2. Arranged thruster (right) five DOF (left)

Figure 3 shows the camcorder model and the manufactured pressure vessel which are installed at the front of the developed robot. As mentioned, the developed robot uses visual inspection method. Therefore, the performance of visual sensor is crucial to execute the inspection tasks successfully. Traditional underwater cam has a low picture quality and insufficient function to obtain image effectively in underwater environment. Especially almost underwater cam shows low performance, because it is impossible to control image focus. For this reason, the camcorder is used to replace underwater cam in the developed system. A pressure vessel is made to use the camcorder in underwater environment. This vessel was verified through inner pressure test of 150m (15bar), because working depth of the robot is 100m (10bar). By locating the camcorder within the pressure vessel, it can be used to perform the inspection tasks successfully in underwater environments.

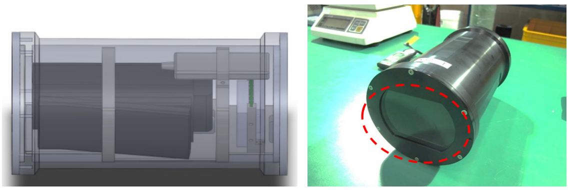

Fig. 3. Camcorder solid model (right) and camcorder pressure vessel (left)

2.2 Design and Implementation of System

The developed robot is equipped with various sensors. The equipped sensors are mainly classified by the sensors for localization and them of health monitoring as shown in Figure 4. The sensors for localization purpose are composed of AHRS (Attitude and Heading Reference System) to measure pose of the robot, DVL (Doppler

Velocity Log) to measure the movement, and a pressure sensor to measure the depth. The sensors for health monitor are composed a temperature sensor to measure heat inside vessel, and a humidity sensor to detect water leakage.

Localization sensor

Robot health sensor

Fig. 4. Second version of lamp actuator

Figure 5 shows a communication diagram of the developed robot. The robot is equipped with a sub-processor which collects and transmits sensor data to the main processor and receives control commands from the main processor. The communication of internal sensors and the sub-processor in the robot is based on a serial communication. The serial communication, this method uses each communication port. This method is inefficient to maintain each communication port. For this reason, to combine communication in this system is advantage and efficient. This role is assumed serial device server. This device combines communication ports to convert from serial to LAN. Obtained image to use camcorder is transmitted by optical fiber communication to generally use image transmission. The tether of ROV is designed for this communication method to include power cable, LAN cable, and optical fiber cable

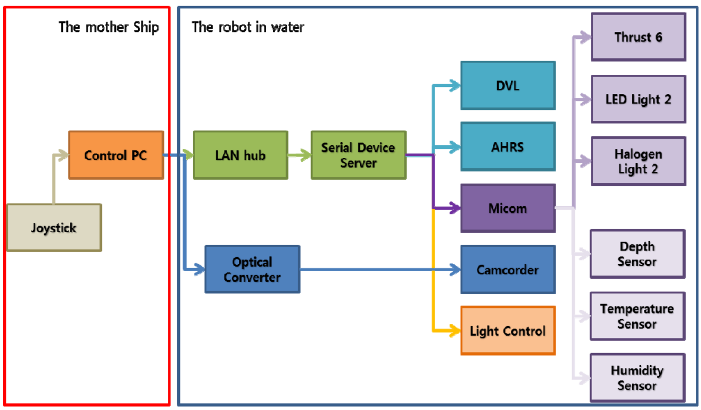

Fig. 5. Communication of ROV system

Figure 6 shows a software structure to operate the developed system. The software structure consists of several separate classes corresponding to each function. It is divided into a communication class, a mission class and a GUI. The communication class collects sensor data and transmits the order of operator by the serial communication. The mission class estimates position data of the robot to use collected sensor data. This localization Class is especially important because we have to know where the inspection image is obtained [6]. It makes command to operate the robot by the order of operator. The GUI performs a general role to represent state of the robot and to transmit the order of operator to the mission class.

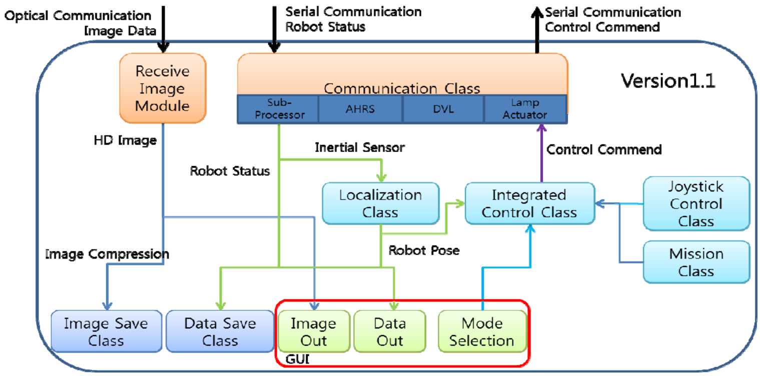

Fig. 6. Structure of system software

Figure 7 shows a pattern board, a LAN hub, and a serial device server. The pattern board is designed to connect devices of the robot to serial device server. This board includes the sub-processor to control thrusters and to collect data of health monitor sensors. Moreover, it performs to control supplying power to control relay switch in the board. This board is located in main pressure vessel.

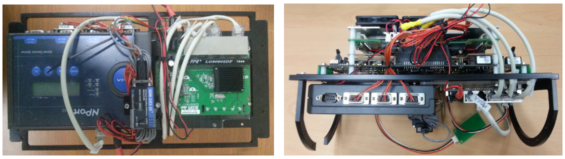

Fig. 7. Robot pattern board and LAN hub, serial device server

3 Experimental Results

Experiments were conducted in a basin to verify the performance of the developed robot. Figure 8 shows the basin where the experiments were conducted. The experiment tested the performance of heading and position keeping algorithms when disturbances were affected to the robot. The pose keeping function is essential to improve the efficient of inspection because the robot should keep the heading and position toward target objects [7].

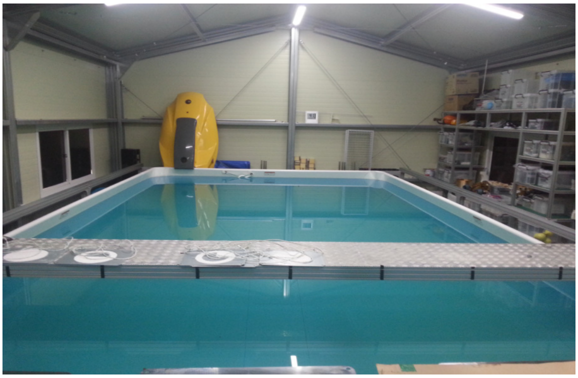

Fig. 8. Environment of experiments (water pool, KIOST in Korea)

For the experiment, the pose of the robot was acquired based on the localization sensors, and a conventional PID control based pose keeping algorithm was used. The heading data of the robot was obtained from the AHRS sensor and the position data of the robot was calculated by integrating velocity data from the DVL sensor.

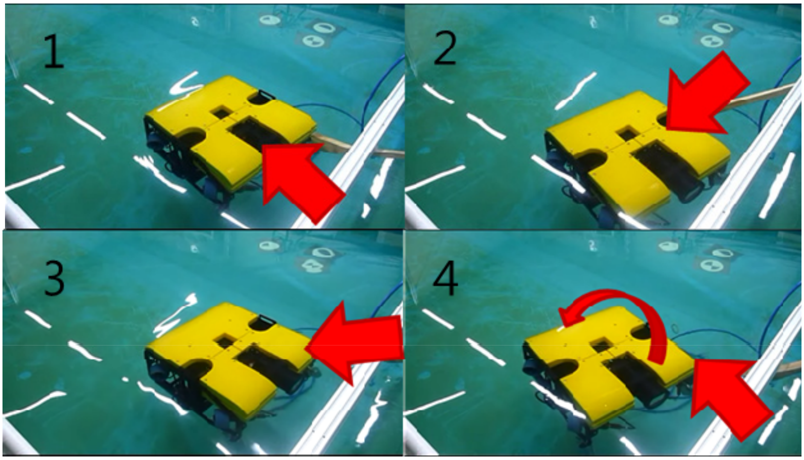

Fig. 9. Disturbance test to confirm performance of keeping algorithm (Backward, Right, Backward & Right, and Rotational displacement)

The disturbance was generated by applying forces to a desired direction. Figure 9 shows the directions of the applied disturbance to confirm the performance of keeping algorithm. Single direction disturbances, which are a backward disturbance (-x direction) and a right direction disturbance (+y direction), were applied first. Then, disturbances of right-backward direction and rotational displacement were applied to confirm the performance of the pose keeping algorithm under the complex disturbances.

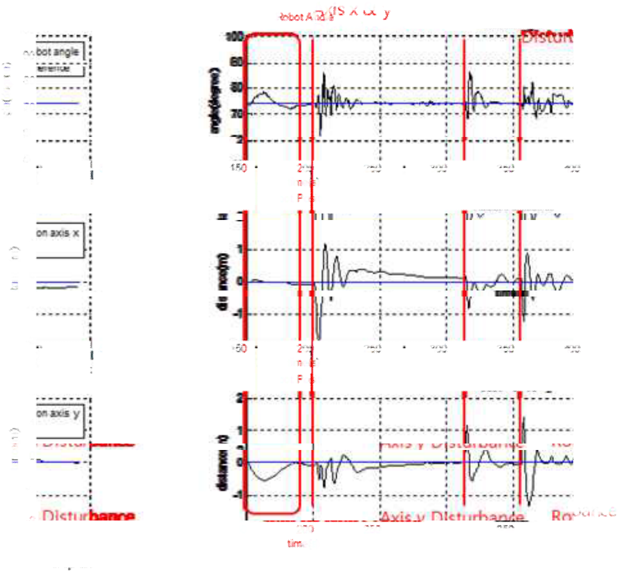

Fig. 10. Motion of robot by heading and position keeping

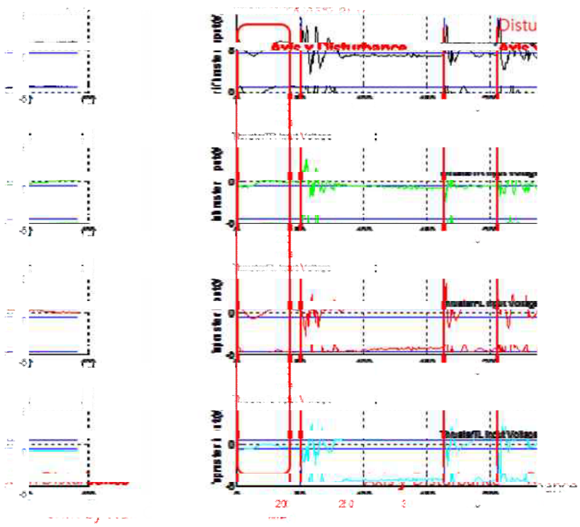

Fig. 11. Thruster input voltage by heading and position keeping

Table 1. Movement of the robot by thruster direction

		Movement of the robot									
		Front	Back	Right	Left	FR	FL	BR	BL	RR	RL
Thruster	FR	+	-	-	+	0	+	-	0	+	-
	TR	+	-	+	-	+	0	0	-	+	-
	FR	-	+	-	-	-	0	0	+	+	-
	TR	-	+	+	+	0	-	+	0	+	-

(FR: Front & Right, TR: Tale & Right, FL: Front & Left, TL: Tale & Left,
RR: Rotate Right, RL: Rotate Left)

Table 2. Direction of thruster and disturbance in experiment of keeping test

		Direction of disturbance			
		Back(axis x(-))	Right(axis y(+))	Back & Right	Rotate right & Translation
Thruster	FR	+	+	+	-
	TR	+	-	Small	Small
	FR	-	-	Small	-
	TR	-	+	-	-

Table 1 show to move the robot by direction to operate thruster. Table 2 represent direction of thruster in experiment of keeping test. Each controller that is composed axis x, y, and rotation decides control input when the robot is moved. These control input are decided control input of each thruster to combined by thruster position. Each thruster is operated by the decided control input. As a result of movement, we confirm that the thrusters operate in the opposite direction of movement. For this reason, the robot is return to original position and heading by keeping algorithm. So, thrusters have thrust in reversed disturbance direction as table 2. Performance of the keeping algorithm is good through that the robot move to original position and heading. The performance of algorithm is not optimization, because purpose of this experiment is to confirm that the robot is suitable moved by keeping algorithm.

These experiments are to overcome dead zone of thruster by null control input to supply 1V to thruster. But the robot is moved by not same output to supply same control input to thrusters as figure 11. The control input is generated by this movement. So the null control input is reduced until dead zone of thruster. To maintain control input voltage by null control input is advantage to rapidly effect control input by PID controller to thruster in the robot.

4 Conclusion

This paper described development of an underwater robot to be specialized in the inspection of underwater structures. ROV was selected as type of the underwater robot, because it has excellent working time by stable supplying power and enables to transmit high quality images by a tether. Moreover, a camcorder was used as a visual sensor instead of a traditional underwater cam. The camcorder is possible to effectively obtain image in underwater by auto focusing and definition of high performance. The developed robot was tested by experiment to confirm the dynamic performance in basin.

Future research will be to verify performance of visual sensor with camcorder by experiment. And algorithm will be developed to assist inspection of underwater structures. Algorithms for efficient control of the robot will be developed. To keep depth of the robot in the water and to verify tidal current is will be made. Additional, sensor of the robot is processed to improve performance. Algorithm to estimate the robot pose to interpolate error to obtain incorrect result of AHRS by magnetic field of structures will be developed to use image of structures.

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