Development of a Low-Cost Underwater Robot for Research and Education

Takuya Fujinaga
Fukuoka University
8-19-1 Nanakuma, Johnan, Fukuoka 814-0180, Japan
E-mail: t.fujinaga.wz@fukuoka-u.ac.jp

Abstract

Underwater robots are utilized for underwater observation. Generally, the development of underwater robots demands a significant amount of funds, posing a high barrier for research, development, and education. The aim of this study is to reduce these barriers, facilitating broader implementation of research, development, and education in the field of underwater robotics. This paper describes the development policy and cost of a low-cost underwater robot and discusses considerations based on the results in the robotics competition.

Keywords: Underwater robot, Underwater drone, Remotely operated vehicle, Low-cost, Robotics competition

1. Introduction

Underwater robots are used as a means of underwater observation. Research and development of underwater robots has been studied since the 1960s [1]. Recently, underwater robots are called as underwater drones and become spread to society. When using underwater robots as tools for underwater geological and biological surveys etc., it is beneficial to use commercially available underwater robots. However, when underwater robots are the subject of research and development or education, the specifications required for the robot vary depending on the purpose. Therefore, it is necessary to develop the robot independently. Underwater robots come in a variety of sizes, from large to small, and research and development has been carried out depending on the purpose [2], [3]. There are also underwater robots developed for education [4].

Generally, the development of underwater robots demands a significant amount of funds, posing a high barrier for research, development, and education. Although some underwater robots have been developed for low-cost, the development cost still ranges from $4,000 to $15,000 [5], [6], [7]. Underwater robots differ from robots that move on land or in the air, and the following are the minimum requirements for their development: watertightness, pressure resistance, and adjusting buoyancy etc. There are also various types of tacit knowledge.

The aim of this study is to reduce barrier of the development cost, facilitating broader implementation of research, development, and education in the field of underwater robotics. This paper describes the development policy and cost of a low-cost underwater robot and discusses considerations based on the results of the robotics competition.

2. Method

2.1. *Development policy*

Underwater robots are mainly classified into five types: glider, cruise, hovering, biomimetic, and vehicle. The selection of each type is determined by the target work and research policy. The glider-type generally does not have propulsion devices and can adjust their own buoyancy and center of gravity, enabling long-term observation. The cruise-type has a long and slender structure, so it has high propulsion efficiency and can conduct wide-ranging surveys. The hovering-type can perform more complex movements than the above-mentioned types by attaching multiple propulsors, making detailed observations possible. The biomimetic-type imitates the characteristics of fish and other animals, can be propelled by fish fins rather than propellers, and are superior to the above types in terms of energy efficiency and consideration for marine life. The vehicle-type can move on the seabed or on the hull of a ship and perform work on those surfaces, such as digging and cleaning. This study adopts the hovering-type for the purpose of detailed underwater observation. The underwater robot developed in this study is designed to operate underwater for about 30 minutes to 1 hour, targeting shallow part of the ocean with an observation depth of 10m or less.

The main components of the hovering-type underwater robot that performs underwater observation are as follows: computers, sensors, thrusters, energy sources. The computers control the underwater robot by controlling the propeller, acquiring sensor information, and selecting the actions. There are various types of sensors depending on the purpose of observation, such as cameras and acoustic devices. Underwater robots also require positioning and navigation equipment and sonar sensor to measure their own posture, position, speed, and surrounding environment. In some cases, sensors account for a large portion of the development cost. Electric thrusters are generally used as propulsion devices, and a high degree of freedom in movement performance is achieved by attaching multiple thrusters. The energy sources need to be selected appropriately to operate the above-mentioned components at the desired operating time. In addition to the above components, communication equipment, work equipment, ballast, etc. are added as necessary.

The low-cost underwater robot in this study also consists of computers, sensors, thrusters, and energy sources. The sensors are equipped with a camera, depth sensor, and inertial measurement unit (IMU). As an option, add underwater lights to conduct underwater observations. In order to control this robot from the ground and check the data acquired by the robot, the external computer on the ground and the internal computer on the underwater robot are connected with an optical fiber cable, and this robot is moored from the ground using this cable. Therefore, this robot becomes a remotely operated vehicle (ROV). However, the development policy is to make it easy to expand the sensor so that it can be changed to an autonomous underwater vehicle (AUV).

The functional requirements for the low-cost underwater robot are described above. As non-functional requirements, this robot is considered portability and parts availability. For the portability, the design is based on the weight and ease of carrying by one person. To ensure the ease of obtaining the parts, use parts that can be easily purchased at online shopping or home centers. Note that some parts are manufactured using 3D printer and laser beam machining. Regarding the development cost, previous studies has proposed a cost of $4,000 to $15,000 for a low-cost underwater robot. In this study, the development cost is less than $2,000.

2.2. *Low-cost underwater robot*

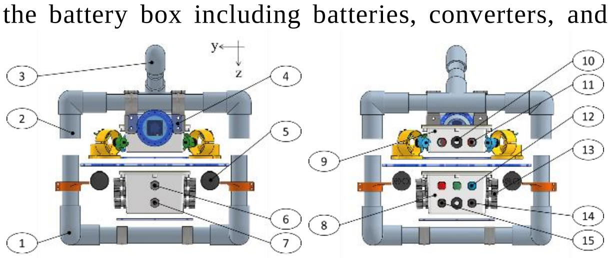
The design drawing of the low-cos underwater robot is shown in Fig. 1, and the components are shown in Table 1. Although, there is a certain distance offset between each component to show the components in Fig. 1, each component is connected as shown in the actual appearance in Fig. 2. This robot mainly consists of the following.

- Frame (No. 1 and 2 in Fig. 1)
- Main box (No. 8) that stores the computers, depth sensor, IMU, etc.
- Battery box (No. 9) that stores the batteries and circuits
- Thrusters (No. 21 and 22)
- Camera unit (No. 4)
- Underwater lights (No. 5)
- Acrylic plates and joints to connect the above components (No. 16-19)

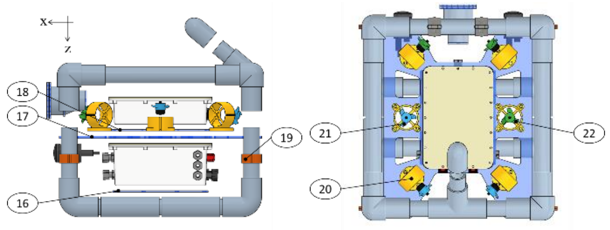
The energy from the battery box is supplied to the main box via cable gland. A total of six thrusters are installed, total of four ones in the front and rear for movement in the xy-plane, and two in the center for movement in the z-axis direction. The camera unit is independent from the main box, and the data is acquired by connecting its power and signal lines to the main box. Each box has holes for cable glands, and the number of holes can be increased or decreased as the number of sensors or thrusters changes, ensuring expandability. Additionally, when this robot adjusts its buoyancy, it fills the poly vinyl chloride (PVC) pipe of the frame with fresh water to maintain neutral buoyancy. A cap (No. 3) is provided to make it easy to put in and take out the water.

The specifications of this robot are shown in Table 2, and the system architecture is shown in Fig. 3. This robot is a size and weight that can be carried by one person. In terms of watertightness and pressure resistance, it can withstand water depths of 1.5m for 30 minutes. Testing at deeper water depths is a future task. To access the internal computer from the external computer, the ethernet connection is converted to an optic fiber connection inside the main box, and the signal is transmitted to the external computer through the optical fiber cable. The external computer is paired with the joystick device via Bluetooth, and the operator can remotely control the underwater robot by operating the joystick device. The internal computer is connected to each sensor and a micro controller unit (MCU). The MCU sends signals to the electronic speed controllers (ESCs), which controls the thruster speed, and to the underwater lights and indicator LEDs. The LEDs are installed to check the on/off status of the internal computer and the operating status of this robot. Fig. 4 shows the circuit architecture inside the battery and main boxes. The battery box has two power supplies: 11.1V for the thrusters and underwater lights, and 5V for the computer and optical media converter. Note that 5V is converted from 7.4V batteries. For the software, this robot distributes processing between the internal computer and MCU and the external computer (Fig. 5). The former acquires data from each sensor and controls the thrusters, underwater lights, and indicator LEDs, while the latter sends commands to the underwater robot and analyzes the acquired data. This robot realizes distributed processing using robot operating system (ROS).

The development cost for this robot is approximately $1,800 (250,000 yen). The proportions of parts by categories are as follows: 6.0% for the frame, 9.6% for cable-related parts, 30.4% for the main box including internal computer, MCU, and ESCs, etc., and 6.8% for the battery box including batteries, converters, and relays, etc., 8.0% for thrusters, 13.6% for sensors, 17.6% for underwater lights, and 8.0% for other including mechanical and electronic parts and 3D printer materials. The frame is used PVC pipe. Products from *TAKACHI Electronics Enclosure* Co., Ltd. are used for the cable gland, main and battery boxes. The internal computer is Jetson Nano and the MCU is Arduino Micro. The type of battery is LiPo. The thruster is a brushless motor for drones, and the motor has a rotation speed of 3100rpm per unit voltage when no



(a) Front view (b) Rear view



(c) Side view (d) Top view

Fig. 1 Design of a low-cost underwater robot (see Table 1 for legend)

Table 1 Components of a low-cost underwater robot

No.	Component	No.	Component
1	Lower frame	12	Indicator LDEs
2	Upper frame	13	Cable gland for thrusters
3	Cap	14	Cable gland for the underwater lights
4	Camera unit	15	Depth sensor
5	Underwater Lights	16	Plate for fixing the main box
6	Cable gland for the camera unit	17	Plate for connecting the two boxes
7	Cable gland for a signal line	18	Plate for fixing the battery box
8	Main box	19	Joint for fixing the two boxes
9	Battery box	20	Thruster guards
10	Cable gland for a power line	21	Thrusters for clockwise propellers
11	Switches	22	Thrusters for counterclockwise propellers

load is applied. The ESC, camera, depth sensor, etc. are products from *BlueRobotics*. The IMU is used BNO055 produced by *BOSCH*.

3. Results and discussion

To evaluate the performance of this robot, it participated in an underwater robotics competition held on October 7, 2023 [8]. This robot entered in the AUV category, but its operation method was ROV. The field of this competition consists of the following areas: for slaloming between buoys, for passing through gates, for observing, for searching an acoustic source, for floating. This robot challenged areas other than the searching an acoustic source area. Fig. 6 shows the depth data and yaw angle data during this competition. This robot started to dive into the field (Fig. 6), moved on the bottom ((ii)), traveled the slaloming area ((iii)), passed the gate, and observed the target ((iv)). Then, this robot turned its direction of travel toward the starting point, that is, rotated its heading 180 degrees, and returned to the starting point. Finally, this robot attempted to float, but the fuse for the 11.1V blown, making it impossible to continue and the trial ended.

The results of this competition confirmed that this robot was able to move on the xy-plane at a speed of approximately 0.15m/s. Fig. 6 showed that the depth and posture of this robot could be measured using each sensor. In the observation area, the USB camera inside this robot was able to read the target panel with QR code and numbers printed on it. On the other hand, regarding the movement in the z-axis direction, the xy-plane of this robot has a larger square measure than other planes, so the underwater drag during floating or diving is also large. For this reason, the load on the thrusters was greater in the z-axis movement than in the xy-plane one, and the fuse worked as a safety measure.

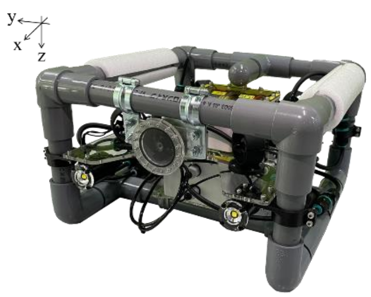


Fig. 2 View of developed low-cost underwater robot

Table 2 Specifications

Dimensions	410 x 400 x 240mm (L x W x H)
Weight	7.0kg (8.0kg when the pipe is filled with water)
Batteries	11.1V, 2.2Ah x 2, 7.4V, 2.2Ah x 2
Computer	CPU: Quad-core ARM A57 @ 1.43GHz, Memory: 4GB
Sensors	USB camera, Depth sensor, IMU
Communications	Ethernet, Optical LAN

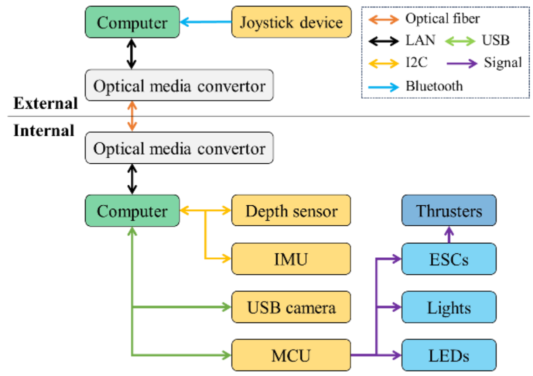


Fig. 3 System architecture for in/external of this robot

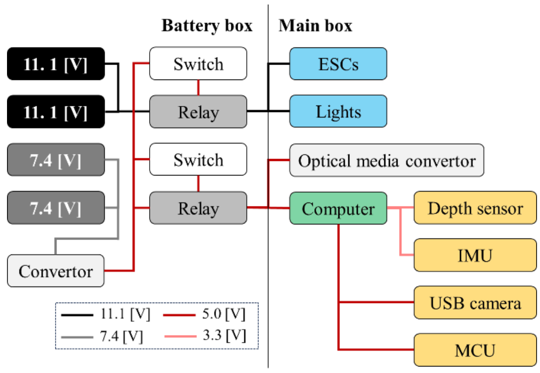


Fig. 4 Circuit architecture

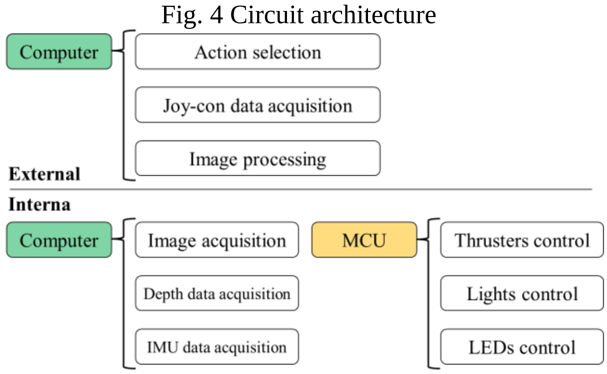


Fig. 5 Software architecture of in/external computer

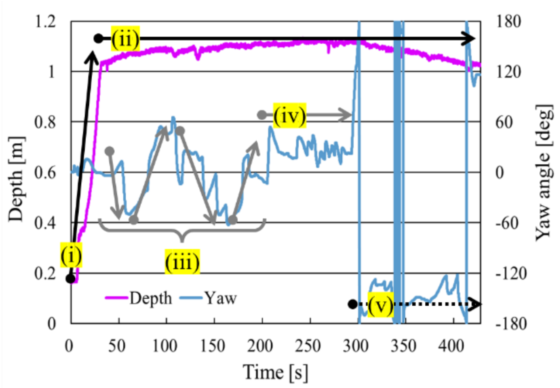


Fig 6 Results of depth data and yaw angle

This robot used a glass tube type fuse, and the holder for it is made of resin. During test before this competition, the plastic holder melted due to the heat generated by the load caused by the rotation of the thrusters. Therefore, as a safety measure, a 5A fuse was used. However, when designing this robot, cables were selected with a permissible current of 15A. Based on these findings, future tasks for this robot include reconsidering the shape of this robot and redesigning the circuit inside the battery box so that it can move in the z-axis direction. Additionally, the purpose of this study is to develop a low-cost underwater robot platform and make it open access. Towards this end, future tasks also include conducting pressure tests, implementing depth and heading control, dead reckoning, and underwater object detection using each sensor.

4. Conclusion

This paper described the development policy and cost of a low-cost underwater robot. This robot was a hovering-type and ROV. The development cost was $1,800. This paper analyzed the sensor data and discussed the motion performance based on the results in the robotics competition. The next tasks are to improve motion performance in the vertical direction and make it an AUV using sensor data. The goal is to open source the requirements and tacit knowledge for the development of the low-cost underwater robot.

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Author Introduction

Dr. Takuya Fujinaga

He is an Assistant Professor at the Department of Electronics Engineering and Computer Science, Fukuoka University, Japan. His research interests are in agricultural robots, underwater robots and field robotics.