Design and Development of an X4-ROV

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***Abstract*—Remotely operated vehicle (ROV) is an unmanned underwater vehicle (UUV) used for conducting underwater task to replace a human diver in the risky job. X4-ROV is a micro observation class ROV to be used mainly for visual observation of underwater structure or environment by utilizing a high definition web camera. The designed vehicle structure was aims towards portability and maneuverability in attitude motions of roll, pitch, and yaw, and the translational motion forward/reverse/lateral. This work explains the use and modification of an open-source platform (OpenROV) into X4-ROV system.**

Keywords—underwater technology; X4-AUV; OpenROV

I. Introduction

Remotely operated vehicle (ROV) is a type of the unmanned underwater vehicle (UUV) use in underwater exploration for carrying out the hazardous task in challenging environment [1]. The demands for these vehicles become significantly high during 1980 and were made by oil and gas industry [2]. In a few years later, an extensive research and development for UUV are done for deployment in many areas of interests. Currently, unmanned underwater vehicles are used in research and deployment for many fields of operations. In the maritime sector they are used to inspect a ships' hull condition [3]. Use in the oceanographic discovery and water pollution research in the science field [4][5] and most ROV is deployed for commercial undersea operation as seen in oil and gas or telecommunication industry [6].

Another class of unmanned underwater vehicles mostly used for underwater study is autonomous underwater vehicles (AUV). The difference of AUVs and ROVs is that AUVs are controlled automatically by on-board computers and can work independently without connecting to the surface. ROVs, on the other hand, are controlled or remotely controlled by the human operator from a cable or wireless communication on the ship or on the ground [7].

An observation class unmanned underwater vehicles priority is real-time data telemetry between vehicles and operator for a successful mission, the presence of human operator makes complex multi-objective underwater missions possible: humans can react to sudden changes in a mission plan caused by the unpredictable nature of the ocean environment [8]. AUV, however, are more suitable for a pre-determined mission where data collection is the main goal and operator intervention is unnecessary [9]. Furthermore, due to the limitation of the advance technology AUV is still limited in both autonomy and capabilities. For this purpose, a ROV system is a definite choice for a given task. Commercially modern ROV systems can be categorized by size, depth capability, onboard horsepower, and whether they are all-electric or electro-hydraulic.

Generally, commercial ROV is group into four categories small, medium, heavy, and seabed class. The small class consists of micro and mini ROV with power less than 5hp use for the shallow underwater observation that carrying a camera for observation or inspection. The medium class ROV is that power up to 50 hp. They are the larger size and durable construction to handle more pressure in the water, step up in propulsion size and increased payload, and usually fitted with manipulators to give them ability in handling some objects. The heavy class ROV is the vehicle with typical power less than 220 hp, they are heavy duty vehicle use to perform more challenging tasks, and typically fitted with multiple tools and manipulators to carry out specialize tasks. Seabed class is highly specialized vehicles use to lay undersea pipes and cable on seabed power at least 200 hp.

This paper is divided into five sections. The first section explains generally on ROV system. The second section will be the X4-ROV development. The third section is about X4-ROV design and development of the prototype and at fourth section is for discussion. Finally, the conclusion section reiterates the main contributions of the work and highlights some of the possible future improvements.

II. X4-Rov Development

ROV system performance is a delicate balance between design and operational characteristic trade-offs. They are formed by a highly interrelated group of the subsystem to provide impressive subsea capabilities. The design of X4-ROV is based on a few operational goals: low cost, high mobility/portability, and live data streaming (video feed).

The project is divided into two major parts which are mechanical design, and electronic/software development. The overall vehicle system is shown in Fig. 1.

A. Hull Design

X4-ROV is a type of ROV with a torpedo hull shape and is driven by four thrusters allocated on the side of the fuselage at equal intervals. Assigning the thrusters on the side of the fuselage is a key point, when controlling the motion and attitude of the fuselage in 6-degree of freedom (DOF) as in Fig. 2.

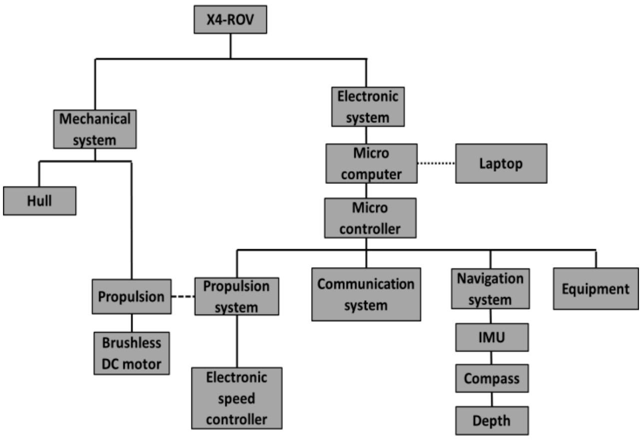

Fig. 1. X4-ROV system

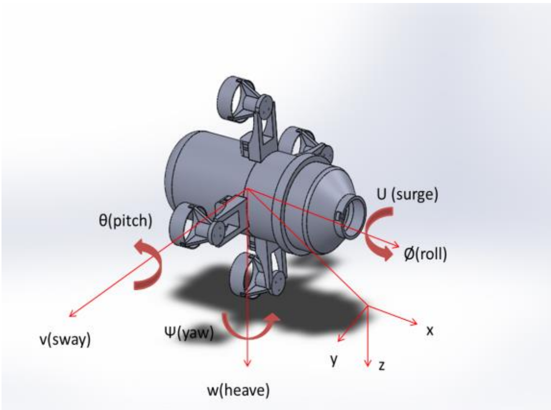

Fig. 2. X4-ROV

X4-ROV has four thrusters arranged vertically and horizontally to control the position by itself using the difference in thrust generated by the thrusters. The X4-ROV hull in Fig. 3 is designed using SolidWorks.

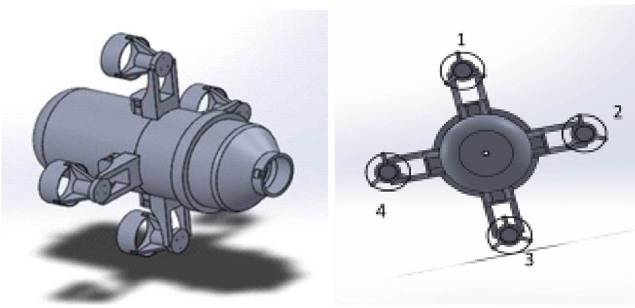

Fig. 3. SolidWorks drawing for X4-ROV

To simplify the development process, a prototype of X4-ROV shown in Fig. 4 is constructed using a PVC pipe, laser cut acrylic, and a few 3D printed parts for testing of system operation and to produce the platform so that further testing and experiments can be conducted.

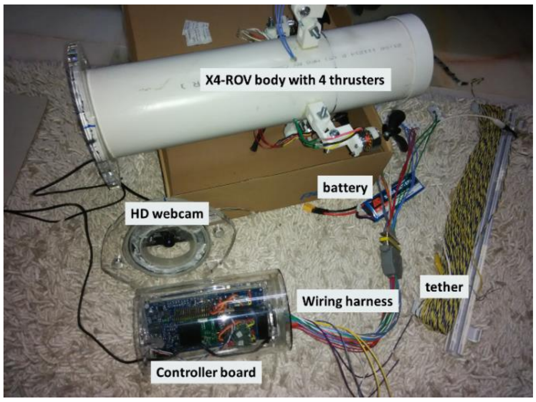

Fig. 4 (a)

Fig. 4 (b)

Fig. 4 (c)

Fig. 4. Cylinder hull from PVC; (b) laser cut acrylic as watertight flange; (c) 3D printed part for thruster mounting

B. Electronic System

OpenROV [9] is a mini observation class of ROV which has the advantage of compact size and weight as shown in Fig. 5. It could stream HD video to a laptop at the ground station over an ultra-thin two-wire tether. Besides that, OpenROV can dive to a depth of 100 meters (328 ft) and the intuitive control system allows for smooth movement [9].

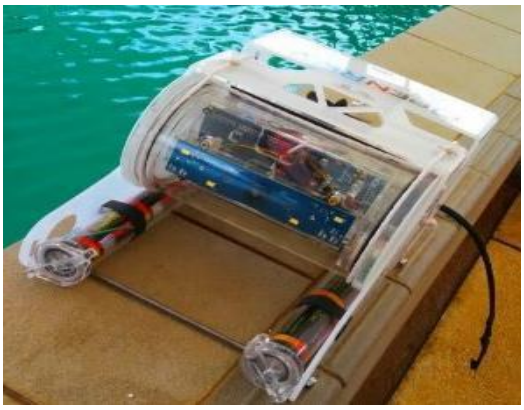

Fig. 5. OpenROV

OpenROV is based on open source platform where a user can work collaboratively with each other to improve user experience and push the ROV system beyond its limitation. Although a user could purchase a fully functional ROV with the do-it-yourself (DIY) style kit.

There is a few modified version of OpenROV platforms have been developed such as Kevin_K ROV in Fig. 6[10].

Fig. 6. Kevin_K Work class ROV

X4-ROV is controlled from the ground station by using a laptop connected to the vehicle using umbilical cable. Fig. 7 shows the block diagram of the X4-ROV electronic system.

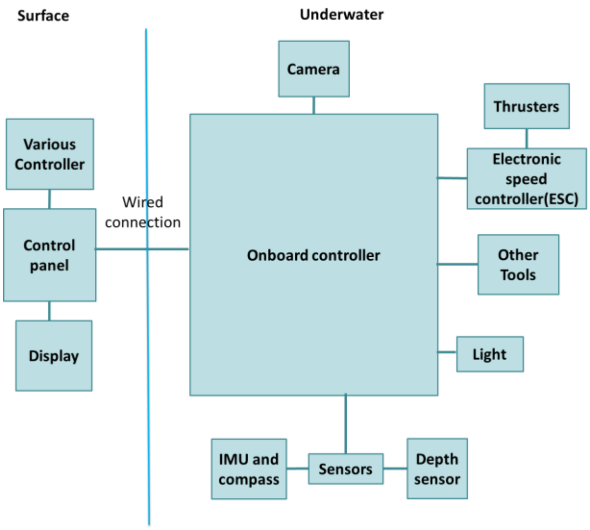

Fig. 7. Electronic system block diagram

The onboard controller consists of two main electronic systems working together as a brain, and nerve system of the X4-ROV. The microcomputer, Beaglebone handles higher level tasks, such as running the webserver that hosts the cockpit page/software, acquiring the video stream from the webcam over USB. The controller board (based on ATMega2560) however is a host and linked to many different electronic parts, such as sensors, power circuitry, and the electronic speed controller (ESC). The OpenROV controller board is modified by attaching an extra electronic speed controller to the board before implementing on the X4-ROV.

The modification of the current OpenROV software is made by changing the operator control interface to accommodate the changes made in hardware. Fig. 8 shows the system interfacing, and it is control through cockpit window open in the laptop. The resulting commands are read and convert to appropriate drive signal on the arduino board.

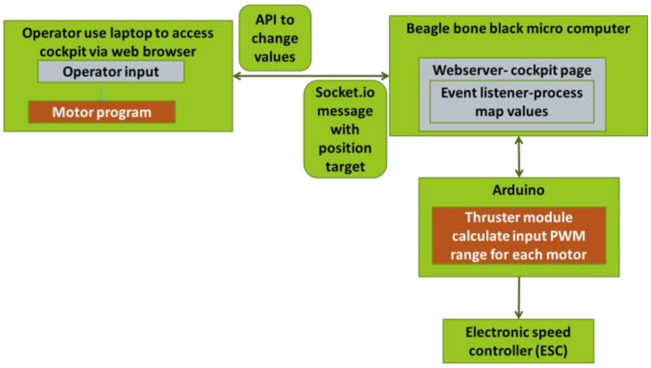

Fig. 8. The ROV system architecture

III. Thrust Requirement for X4-Rov

It is required to determine thrust requirement for the vehicle so that an appropriate motor sizing are met. The thrust of X4-ROV is affected by a force of drag. When a vehicle is moving through the fluid, the immediate surrounding fluid is accelerated along with the body thus affecting the dynamics of the vehicle. Such force is known as added mass where it is depending on the shape of the vehicle, and fluid density [11].

From,

$$F = Ma \quad (1)$$

and the characteristics of added mass, the total mass matrix M of the body can be written as:

$$M = M_f I + M_F \quad (2)$$

where M_b is a mass of the vehicle, M_F is an added mass, I is a 3×3 identity matrix.

For a cylindrical body the added mass in water is given by,

$$M_f = \rho \pi x R^2 L \quad (3)$$

where ρ is a density of the fluid R is radius and L is the vehicle length. Using the cylindrical body specification in Table 3, we calculated that the required thrust for 0.5m/s^2 acceleration is

$$F = (M_b + M_f)a \quad (4)$$

By assuming, $\rho = 1000$ kg/m^3 gives $M_f = 4.086$ kg, M_b (body included electronic parts) = 3.4 kg and F = 3.743 N.

TABLE I. CYLINDRICAL BODY SPECIFICATION

Radius	Length	Mass
55mm	430mm	~1.3KG

The thrust power from the thrusters is measured by using simple test tank setup in Fig. 9. When the motor thrust forward direction a force in opposite direction is produced and can be read on the electronic scale.

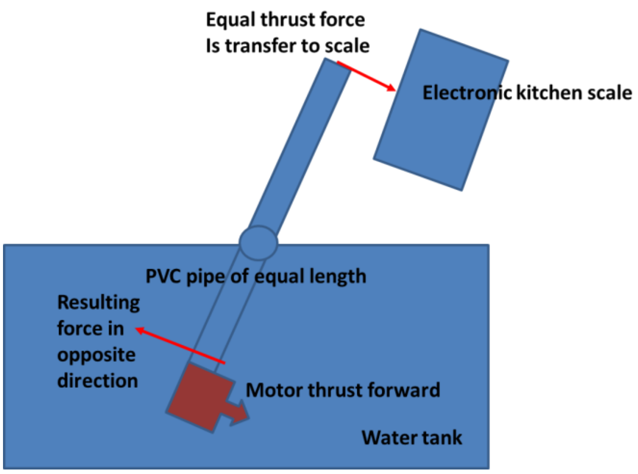

Figure 9 (a)

Figure 9 (b)

Fig. 9. Test tank setup for thrust measurement

IV. Results and Discussions

To demonstrate the pressure impact on the X4-ROV body, the SolidWorks software is used by simulating the water flow (pressure) in forward direction. The Fig. 10 shows the cut plot to demonstrate the body reaction which focused at the tip of the X4-ROV body.

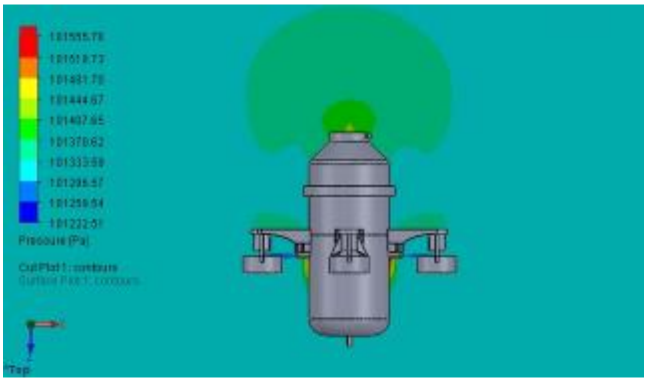

Fig. 10. Cut plot

A surface plot shows the pressure acted on ROV body as in Fig. 11. The precaution should be taken since the region with higher pressure distribution can cause break or leakage on the body. This can be avoided by thickening the body wall.

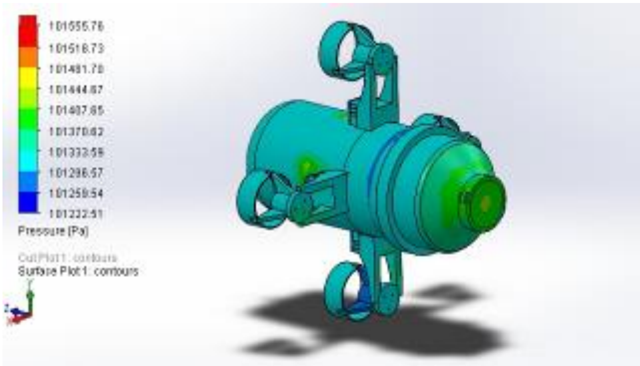

Fig. 11. Surface plot

The water flow trajectory in forward motion is shown in Fig. 12. It is necessary to study the turbulence while moving in the fluid so that the thrust are used efficiently.

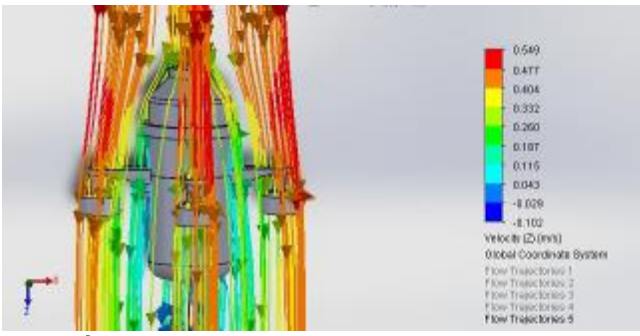

Fig. 12. Flow trajectory

From the test, we manage to plot the thrust of the single thrusters in the water. The maximum thrust obtain is 1.25kg. Test result is shown in Fig. 13.

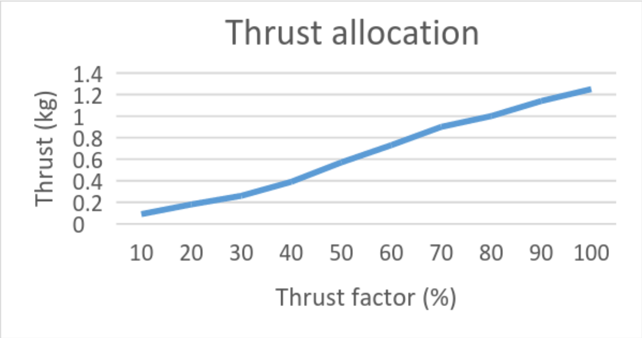

Fig. 13. Thrust in the water

V. Conclusion

The X4-ROV is successfully designed and developed. The initial thrust test result can be further improved. In future, a full testing will be carried out after finalizing the hardware and software integration and the analysis on the sensor output and required motor speed can be conducted.

ACKNOWLEGMENT

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