Hull Design for ROV with Four Thrusters (X4-ROV)

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Abstract—In this research, an X4-ROV consisting of four thrusters is design to develop a small ROV which does not have any rudders for an observation class unmanned underwater vehicle system. Each thruster is arranged at equal intervals to the same plane, and the attitude motions of a roll, a pitch and a yaw, and the translational motion forward are realizable by changing the rotational speeds of four thrusters. In this paper, the construction of an X4-ROV system and the motion method are described, together with the added mass. A torpedo hull shape with four thrusters is draft using solidworks for fabrication of hull (body) shape using a 3d printer. The operator will communicate with ROV via open source platform.

Keywords—ROV; underwater system; hull design.

1. Introduction

Unmmaned Underwater Vehicles (UUV) is a grouping of an autonomous underwater vehicles (AUV), remotely operated underwater vehicles (ROV) and underwater glider [1]. This technology has become an important field of study in underwater research and development to replace human in hazardous underwater operations [2]. During 1980's high demands on unmanned underwater vehicles deployment are made by oil and gas industry when the development of offshore platform exceeds the limits of a human's diver [3]. 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 human operator from a cable or wireless communication on ship or on the ground [4]. Currently unmanned underwater vehicles are used in research and deployment for many fields of operations [4] [5] [6] [7] [8];

- Scientific research of underwater (water pollution, marine life, archaeology)
- Search and rescue mission/air crash investigation (search and rescue victim of japan tsunami)
- Underwater survey and surveillance
- Inspection of commercial undersea facilities and installations (oil n gas industry, telecommunication)
- Various military operations (mine counter measure, retrieve warhead used in training)

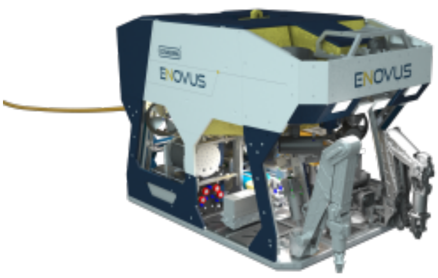
An observation class unmanned underwater vehicles priority is real time data telemetry between vehicles and operator for a successful mission, the presence of human operator makes complex multi-objective underwater missions possible: humans can react to sudden changes in a mission plan caused by the unpredictable nature of the ocean environment [9]. For this, a ROV system is a definite choice for given task. AUV however are more suitable for a pre-determined mission where data collection is the main goal and operator intervention is unnecessary [10].

A basic feature on a ROV includes thrusters, cameras and/or hydrophones (underwater microphones) and various sensors depending on the applications. ROVs can be equipped with many different sensors such as water temperature sensors, depth sensors and sonar. Multiple thrusters and rudders are usually utilized for most of ROVs. The rudders are allocated at the side of the airflame and they play an important role in the control of the position and attitude. However, it is common that effectiveness by rudders worsens in a low-speed cruise, so that the use of rudders is not efficient for a small ROV, which performs especially low-speed operation. From this fact, Watanabe et al. [11] proposed an AUV that the position and attitude of the airflame are controlled by using only the outputs of four thrusters, without using any rudders. The X4-ROV has a merit that the number of degree-of-freedoms (DOFs) in the states can be controlled by using less number of inputs, because the position in three DOFs and the attitude in three DOFs, i.e., totally six DOFs motions can be controlled by any underactuated control method with the thrusts of four thrusters.

Generally, ROV structures are divided into two main categories as describe in Table 1. An ROV with an open frame structure has stable three DOFs motions based on a large metacenter. This type of structure has various additional advantages. This structure is well known and generally adopted by most ROVs. It is convenient for large payloads. Inspection and cleaning equipments can be easily attached to or removed from the body. However, ROVs with this structure have difficulties with motions that require more than three DOFs. Due to these advantages and disadvantages, open frame structure is mainly applied to ROVs for general works. Even though an ROV with a closed frame structure has potential for greater mobility, it has disadvantages. Due to a short metacenter, it has relatively unstable motions. It also has a small payload. It is very inconvenient in handling large payloads for cleaning and inspecting. Thus ROVs of closed frame structure are applied to special works that need fast motions [18].

In the design of the X4-ROV, the body is designed to minimize as much drag reduction as possible. To meet this strategy, an ellipsoidal/torpedo hull shape is designed.

Table 1: Open frame and close frame design of ROV [18]

	Hull with Open frame	Frameless hull (close hull)
Structure type	 Seaeye Falcon[19]  Enovus ROV[20] ROV structure with open frame design	 SAAB Double Eagle SAROV[21]  Deep trekker DTG2[22] Frameless ROV design
Advantage	• Well known structure adopted on most ROV. • Stable 3DOF translational motions based on large metacentre. • Larger payloads and can carry object. • Easier to attach tools and equipment.	• Greater mobility/highly manoeuvre • Typically lightweight and portable • More energy efficient
Disadvantage	• These types of ROV have difficulties with motions requiring more than 3DOFs.	• Smaller payload • Not convenient for attaching tool or equipment

2. X4-Rov Development

A. Underwater vehicle coordinate system

The motion of underwater vehicles will be describe using a special reference frame as shown in Fig. 1. It consists of two coordinate systems; an inertial (fixed) coordinated system and a motion (body-fixed) coordinate system. The coordinate frame {E} is composed of the orthogonal axes {x y z} and is called as an inertial frame. This frame is commonly placed at a fixed place on Earth. The axes x and y form a horizontal plane, and z is the direction of the field of gravity. The body-fixed frame {B} is composed of the orthogonal axes {u, v, w} and is attached to the vehicle. The body axes, two of which coincide with the principle axes of inertia of the vehicles are defined by Fossen [12] as follows: U is the longitudinal axis (directed from aft to fore); V is the transverse axis (directed to starboard); W is the normal axis (directed from top to bottom). Figure shows the coordinate systems of underwater vehicle, which consist of a right-hand inertial frame {E} in which the downward vertical direction is to be positive, and a right-hand body frame {B}.

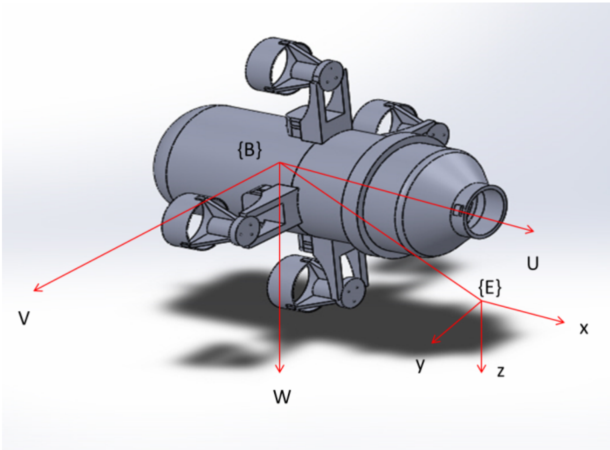


Figure 1: Underwater vehicle coordinate system

B. Overview of a X4-ROV system

X4-ROV is a type of ROV with a torpedo hull shape and is driven by four thrusters allocated in the side of the fuselage at equal intervals. Assigning the thrusters in the side of the fuselage is a key points, when controlling the position and attitude of the fuselage. X4-ROV has four thrusters arranged vertically and horizontally to control the position and attitude of the fuselage, and controls itself using the thrust difference generated by the thrusters. Moreover, since a microcomputer, a sensor, etc. are carried in the body, positioned at the center of the four thrusters, it is a waterproofed container in itself. Fig. 2 shows the prototype of X4-ROV system which currently under development at UMP. It has all the basic features for ROV. It streams HD video to a surface laptop over an ultra-thin two-wire tether with length 100 m. Therefore, X4-ROV can dive to a depth of 100 m (328 ft) .

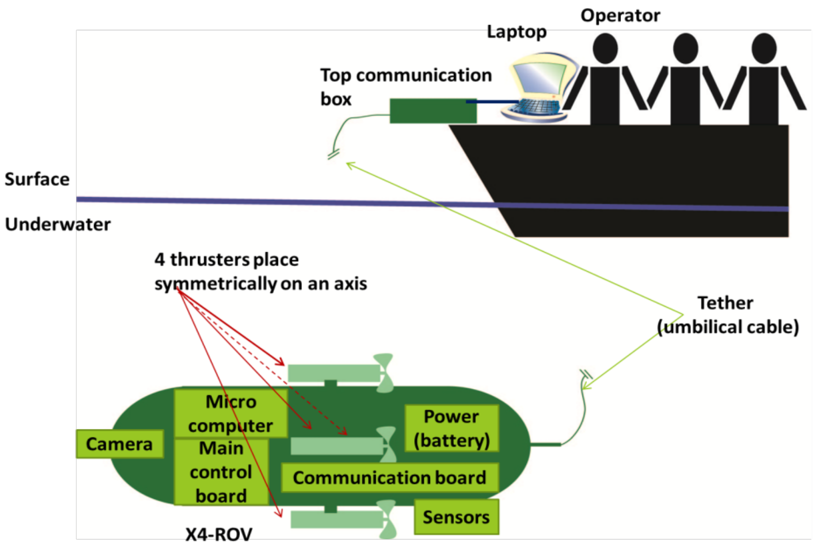


Figure 2: X4-ROV system

The platform uses both a microcomputer and microcontroller board. 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, and more. The controller board however is hosts to many different electronics, such as sensors, power circuitry, and the micro controller. The microcontroller (ATMega2560) is responsible for being the interface to the different sensors and motors. It is connected via UART back to the Beaglebone. Fig. 3 and Fig. 4 show the control block diagram and electronic system use on X4-ROV, respectively.

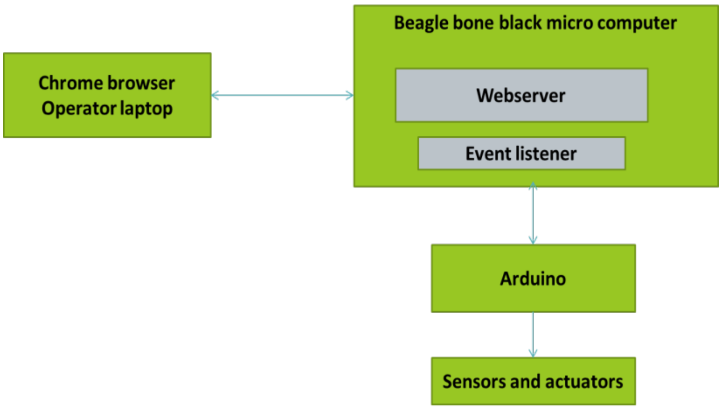


Figure 3: X4-ROV system control block diagram

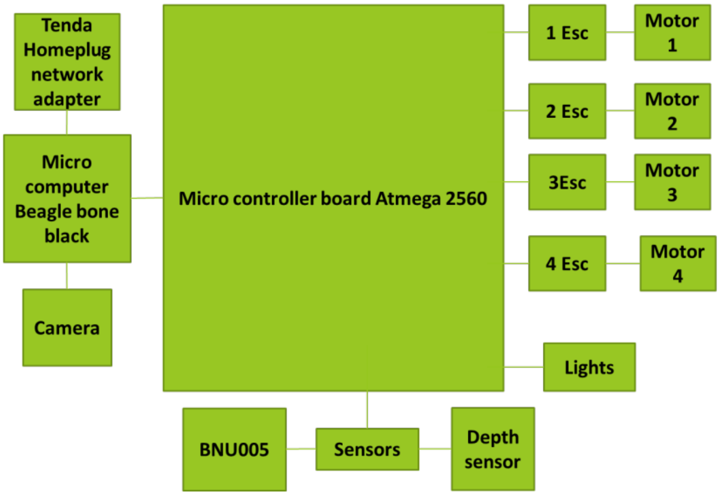


Figure 4: X4-ROV electronic system

C. Mechanical structure

Mechanical structure of a ROV is mostly dependent to its specification (working depth/environment) and operational needs. A typical ROV structure comes with firm frame for mounting or attaching necessary parts and pressure hull [12]. The hull is the ROV main body, it is where all the electronics are kept and protected from water. X4-ROV main feature is for its high portability and maneuverability for inspection/observation missions, for that the only equipment it carries is a camera and light source. This eliminates the needs of frame structure and the development focus solely on hull construction. For an underwater vehicle, water pressure is great concern. A sphere is an ideal hull shape for pressure endurance [12][13]. The idea is that a hull should be asymmetry, however sphere shape exerts much drag on vehicle which would consume energy and reducing power efficiency, and so ellipsoid shape are proposed in [13] to improve drag force. For development, a cylindrical shape is use to simplify development as shown in Fig. 5 and Fig. 6. The hull structure resemble that of AUV, however a conventional AUV uses steering rudders that have lack of control and precision and not capable of making sharp turning radius [14] [15]. Therefore, to overcome the limitation of the vehicle which has only one propeller, in this research, four propellers is presented to provide the thrust and also to accentuate navigation purpose without the use of actuated fins. Without actuated fin the vehicle do not require complex mechanical control linkages for fin actuation, relying instead on fixed pitch propeller and by using variation in four motor speeds for vehicle navigation control [16][17].

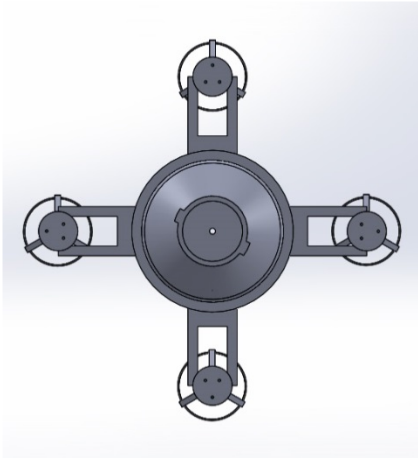


Figure 5: X4-ROV front view

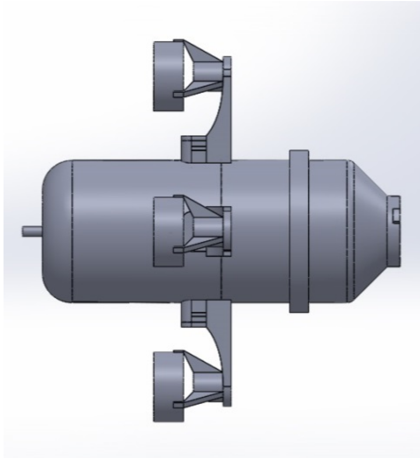


Figure 6: X4-ROV side view

For a submersible vehicle, its thrust is affected by a force in the form of added mass. The phenomenon occur when the underwater vehicle is moving, the immediate surrounding fluid is accelerated along with the body. This affects the dynamics of the vehicle in such a way that the force required to accelerate the water can be modelled as an added mass which depend on the vehicle shape and fluid density [18].

From,

$$F = ma \tag{1}$$

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

$$M = M_B I + M_f \tag{2}$$

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,

$$M_f = \rho \pi x R^2 L \tag{3}$$

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

$$F = (M_b + M_f)a \tag{4}$$

By assuming, ρ = 1000 kg/m^3 gives Mf = 4.086 kg, Mb (body included electronic parts) = 3.4 kg and F = 3.743 N.

Table 2: Cylindrical body specification

Radius	**Length**	**Mass**
55mm	430mm	~1.3KG

3. X4-ROV POSITIONING AND MOTION CONTROL STRATEGY

X4-ROV use a number of 4 thrusters attach to its body to perform the maneuver in 3 dimensional (3D) spaces with 6 degree of freedom (DOF). Fig. 8 shows motion definition for X4-ROV as describe in [17].

A. Rotational motion

The rotational motion strategy of X4-ROV is quite similar to that of quadrotor. The propeller configuration is shown in Fig. 9 below. Table 3 describe the thrusters configuration for yaw, roll and pitch motion.

B. Translation motion

The translational motion of X4-ROV in surge (forward/reverse) direction is rather simple. However, to realize a lateral motion in heave (z) and sway (y) direction will be challenging. The idea to achieve the motion is by vector force where the four thrusters are mounted in angle to create a vector thrust, they are graphically described in Fig. 10. The successful motion shall be clarified during experiment.

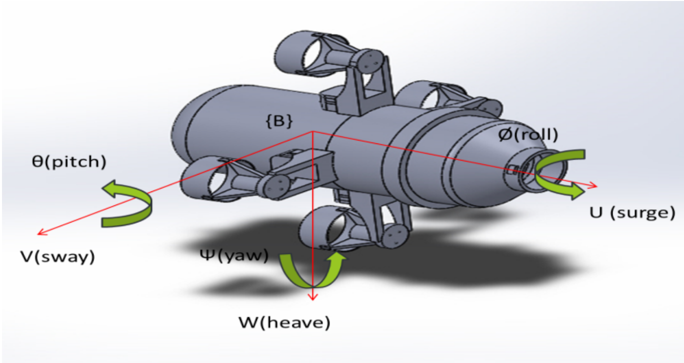


Figure 8: 6-DOF motion definition.

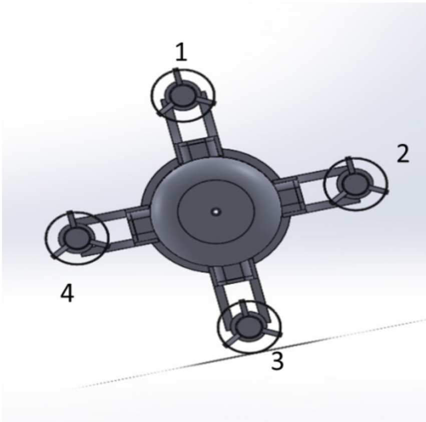


Figure 9: Thruster configuration.

Table 3: Thrusters direction for rotational motion

Thrusters	YAW	ROLL	PITCH
1	High CCW	CCW	High CCW
2	CW	Slow CW	CW
3	High CCW	CCW	Slow CCW
4	CW	High CW	CW

CW – clockwise CCW – counter clockwise

4. Conclusion

In this paper, the design of an X4-ROV system and the fundamental motion has been performed. Next, the real hardware platform will be developed to verify the forward motion of X4-ROV and rotational motion in each attitude.

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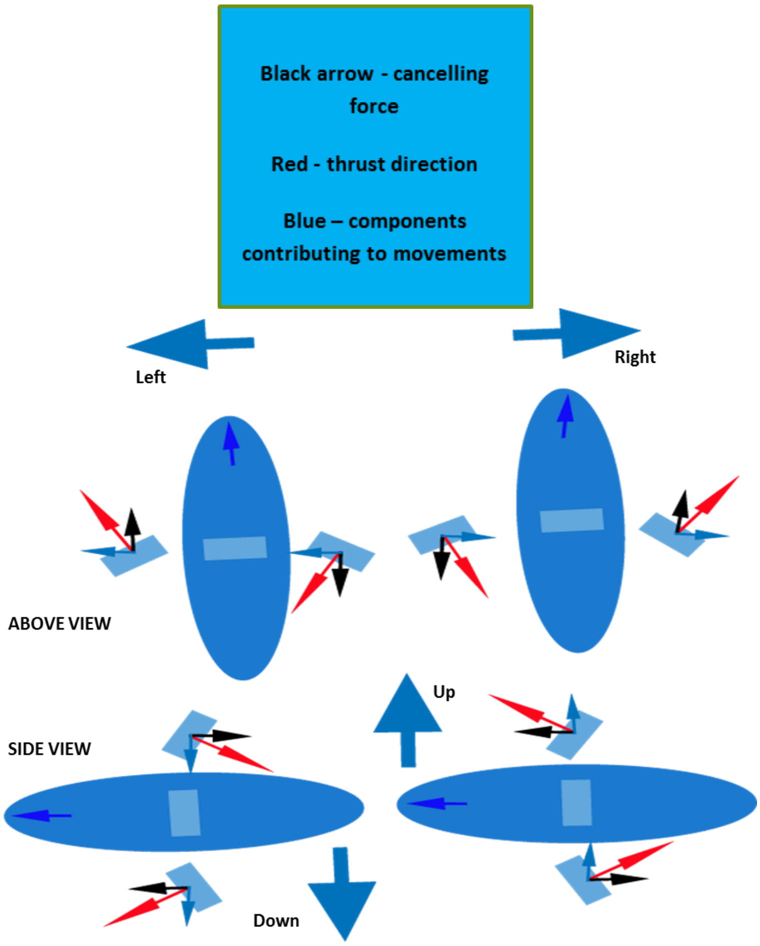

Figure 10: Translational motion strategy.

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