Design and Development of a Remotely Operated Vehicle

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Abstract

This paper describes basic design and development of a mini remotely operated vehicle. It is a custom designed and built vehicle, measures 320mm wide, 500 mm long, 250mm high and it weighs approximately 15kg in air. This underwater vehicle will be used for surveillance and maintenance application. The cylindrical pressure hull with clear acrylic nose has been designed and fabricated, creating efficient use of space to fit electronics unit alongside the camera. Four thrusters for the propulsion system are newly designed and layout, providing surge, heave and yaw motions. Various controls have been built; the 8 bits microcontroller, supplemented with custom power management PCB. Sensing is undertaken through the use of a colour camera, an electronics compass, a pressure sensor and off-the-shelf inertial measurement unit. Two 12 Volt 7.2Ahr lead-acid batteries make up the power for entire system to extend the working range to approximately 1 hour. Implementations of basic movements were done in the pool and at sea.

***Keywords**:* ROV, Underwater, Applications

1. Introduction

The unmanned vehicles such as Remotely Operated underwater Vehicle (ROV) are amongst the most utilised underwater equipments that have been designed and improved for surveillance and maintenance tasks in different applications [1]. ROV is a tether based underwater vehicle which can be deployed for both shallow water and deep see explorations, especially in scientific, commercial and educational purposes. Other deployments of ROVs are underwater monitoring and structure inspection tasks [2]. These purposes replace human as divers, therefore it reduces the risk of human diving into water. In general, ROV can be classified into three main groups [3]: heavy work, general and micro/mini ROVs. Various examples of ROV design are Subjugator of University of Florida [4] and Serafina of Australian National University [5]. Although there are commercial products of ROVs, they are expensive. Thus the purpose of this work is the development of a low cost vehicle. This paper addresses the design of a new ROV, required to bring underwater visual information used for educational purposes.

This paper is organised as follows. Section 2 presents a mechanical design. Section 3 describes the electronic systems. Section 4 details software architecture. Section 5 shows test results. Future works are discussed in section 6. Finally, section 7 presents the conclusion

2. Mechanical design overview

Conceptual design is the first design state. The procedure is based on a basic machine design, strengths of materials and basic naval application. Fig. 1 depicts a final design of the ROV.

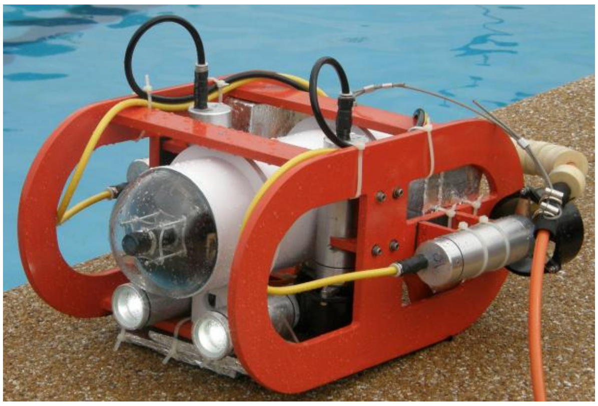

Fig. 1 ROV design

The hull design is described as a torpedo-shape form. It is made up of a thin PVC cylindrical hull with a clear acrylic shell. This hull protects all contained electronic devices from impact and pressure surrounded it. The overall dimension of the vehicle is 500mm long, 320mm wide and 250mm high. Total weight is approximately 15kg in air. The ROV is equipped with various sensors, including an IMU, a colour CCD camera, an electronic compass and a pressure sensor. This provides essential information on both vehicle state and information on the surrounding environment. The use of four custom thrusters gives three DOFs of motion (surge, heave and yaw). Table 1 summarises design specifications of the ROV.

Table 1 Design specifications

Class	mini ROV
Dimension (mm)	500 $\times$ 320 $\times$ 250
Hull (mm)	PVC ϕ 140 $\times$ 300
Weight in air	15 kg
Designated depth	15 m
Buoyancy	slightly positive
Propulsion	4 brushless thrusters
Sensors	IMU, pressure sensor, digital compass
Lighting system	2 LEDs
Vision	1 CCD colour camera

2.1 Pressure hull

A pressure hull is required to contain the electrical systems. A single pressure vessel is designed for this purpose. The hull is assembled from 140mm outer diameter and 5mm thickness PVC tube, a hemi-spherical acrylic shell and a 35mm thickness bespoke aluminum end cap, resulting in a total length of 380mm. The end cap is a special design for water proof with double O-rings.

For the hull's collapse resistance, numerical calculations were done by using the finite element analysis (FEA) software. Table 2 and 3 show hull and hemi-sphere data and results whilst Fig. 2 and Fig. 3 show FEA simulation results.

Table 2 Hull data and results

PVC yield strength	66 MPa
Max Von Mises stress	4.09 MPa

Table 3 Hemi-sphere data and results

Acrylic yield strength	66 MPa
Max Von Mises stress	2.37 MPa

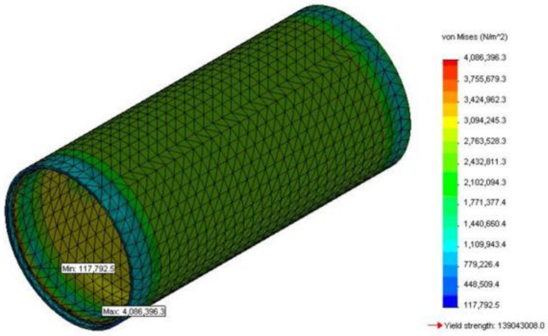

Fig. 2 Hull FEA

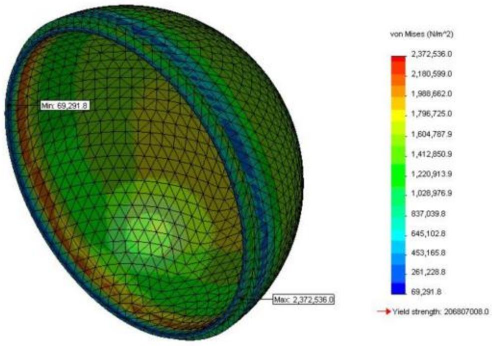

Fig. 3 Hemi-sphere FEA

2.2 Frame

Designing the frame is vital for the ROV, as providing the structure for the hull form and the components. The frame has been designed considering the following criteria:

- Material strength and available
- Ease of production and maintenance
- Light weight
- Centre of gravity of the frame

Each parameter was evaluated. The chosen material is lightweight superlene nylon glued with araldite adhesive formed a frame to mount the pressure vessel and thrusters. This frame proved successful in the test and will be extended to provide supports for multiple pressure vessel and other components.

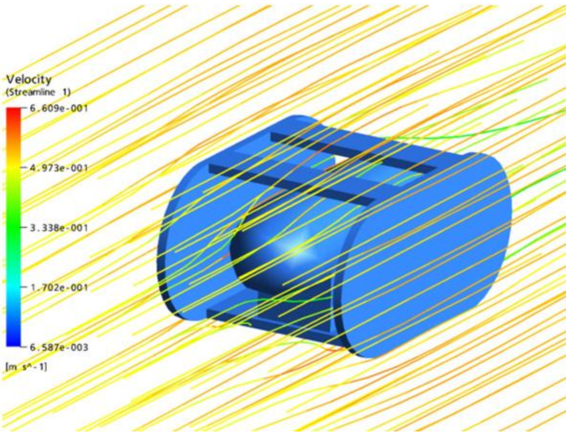

Fig. 4 CFD analysis for drag forces

In addition, the evaluation of the drag forces is considered. Fig. 4 shows the simulation result of fluid flow along the ROV with a desired speed of 1 m/s. The simulation is achieved by using the Computational Fluid Dynamics (CFD) software. The drag force along the *x*-axis is 0.6, whilst the drag force along *z*-axis is 1.18. This would provide initial information to calculate the required power for the ROV's thrusters later.

2.3 Thruster

Four thrusters are used in the ROV. Each thruster has a brushless DC motor sealed in the cylindrical hull connecting to the type-A propeller, shown in Fig. 5. The out-runner type motor with 1280 KV provides marginal enough thrusts during the operations.

Fig. 5 Thruster configuration

This selection of brushless motor avoids the wear problem and easily maintenance. However this type of motor requires sophisticated Electronic Speed Controllers (ESC). They use the standard pulse width modulated (PWM) signal used by all common radio controlled system to set the motor movement. The layout of the thrusters was governed by the mission brief. The suitable compromise between having maximum manoeuvrability and low power consumption was two vertical and two horizontal thrusters. This arrangement of thruster allows control of surge, heave and yaw motions (see Fig. 6). The line of action of the heave direction has to cross the centre of mass in order to avoid roll and pitch movements. The surge/yaw thrusters are parallel and the line of action is the same height of the centre of mess avoiding the pitch moment.

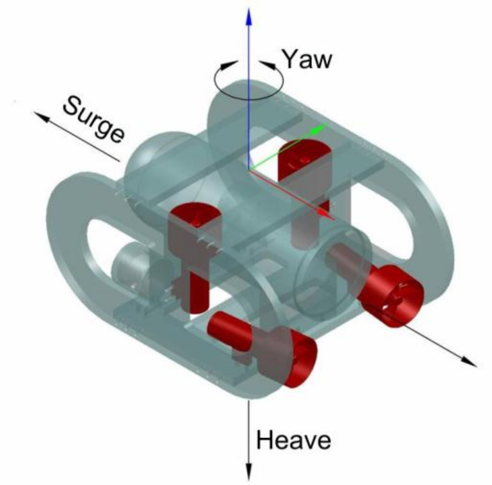

Fig. 6 Thruster allocation

3. Electronics

An overview layout of the electronic system is shown in Fig. 7. The electronics are split into two parts: surface unit and underwater unit. The pressure hull contains main microcontroller, four thrusters with ESC, the navigation system (IMU, depth sensor and compass). The electronics are described in more details in the following sections.

3.1 Microcontroller and computer

The computer with joystick control in the surface unit can be used in common PC type. Whilst the microcontroller used in the pressure hull is the AVR MEGA 1280 chipset with a well known Arduino open-source software package. The AVR MEGA 1280 board has many benefits, as it runs at 16 MHz with 128 Kbyte flash. It contains 54 digital I/O, 16 analogue inputs and 1 USB.

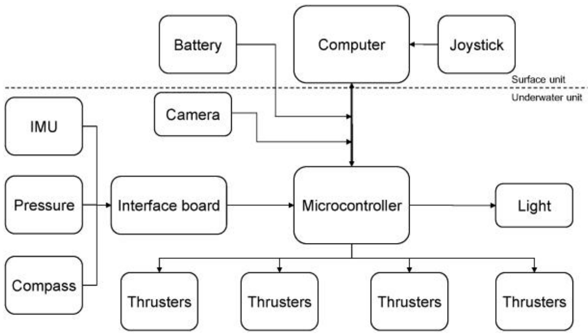

Fig. 7 ROV electronic system

3.2 Navigation

The navigation sensors comprise an inertial measurement unit, a pressure sensor and an electronic compass (see Fig. 8).

3.2.1 Inertial measurement unit (IMU)

The ROV's rotational rates and accelerations are measured using a 6DOFs analogue combo board razor IMU. The board uses a triple-axis accelerometer coupled to a three single axis gyro. The gyro outputs have a full scale of $\pm$ 300 degrees/s whilst the outputs of the accelerometer have $\pm 3g$ range.

3.2.2 Pressure sensor

The ROV depth can be obtained by measuring the local water pressure. The Motorola MPX4250 is used for the measurement. It provides a pressure range from 20 kPa to 250 kPa and thus can measure depths up to 15m. The pressure sensor provides an analogue voltage output between 0.2V and 4.9V, whilst the accuracy is 1.5% error.

3.2.3 Electronic compass

An electronic compass measures the vehicle's heading with a precision of 0.5 degrees, connection to the microcontroller through I/O port. Supply voltage of the sensor ranges 2.7V to 5.2V and the power usage is less than 2mA.

3.3 Camera

A colour CCD camera is fitted at the front of the ROV's hull. The horizontal resolution is 420 TV line. It interfaces directly to the user computer via a cable. The visual information during the operation can be stored by the user.

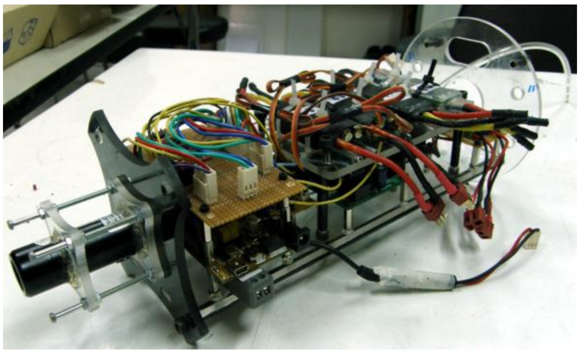

Fig. 8 Electronic system

3.4 Power supply

The power supply built with two 12V-7.2Ahr lead-acid batteries allows working range up to approximately 3 hours. The power system is in a surface unit providing sufficient voltage and current to the electronics and thrusters.

4. Software

The software has been developed using the Arduino open-source programming language in JAVA. Three modules are implemented (see Fig. 9 for a monitoring screenshot). The first module is for monitoring information from sensors. The second one is for receiving visual information. The last one is for the ROV motion control. The full integration of software architecture will be done in future work.

5. Preliminary tests

Two implements have been carried out. Basic motion controls have been tested in fresh water at the university pool. It found that operator can simultaneously control surge, heave and yaw motions. Fig. 10 (a) has shown screenshots during the test. The second tests carried out at the sea are shown in Fig. 10 (b).

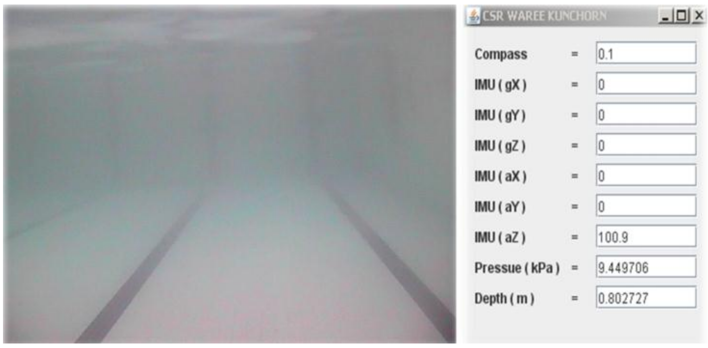

Fig. 9 Monitoring screen allows visual view and ROV's states during the operation

(a) (b)

Fig. 10 (a) Test at university pool. (b) Sea trails at Bangsean, Chonburi

6. Future works

There are numbers of improvement that can be made. Reliable pressure vessel is required for high pressure and larger space for housing the electronic parts. The tether used in this project is not neutral buoyant thus it is needed some modification. Power management system is also needed in the future work. This allows the sensing of voltage and current flow and the management system should protect the battery against fault conditions.

7. Conclusion

The design of a mini ROV is presented in this paper. It has been built to be used as a development vehicle for underwater visual application. Experiments have been successfully done in a pool and sea.

8. Acknowledgements

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