Remotely Operated Vehicle with Depth Control

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Abstract

This research focuses on designing and building Remotely Operated Vehicle (ROV) driven by four propellers and controlled by tethered joystick. The entire system can be transported very easily. This ROV can be used to survey in both fresh and salt water. To increase this ROV's capacity, a depth control has been developed to maintain a constant depth using a PID control. The control system in this robot is implemented by microcontroller along with a pressure sensor, accelerometer and gyroscope, and video camera so that the orientation in 6 degree of freedom can be estimated and underwater environment can be monitored by a user.

Keywords*:* (ROV) Remotely Operate Vehicle, Depth control, PID control

1. Introduction

Recently, underwater vehicles have been employed in several operations; such as, ocean and fresh-water surveying, water sampling, and rescuing operations. The tethered underwater vehicles with manual operation are known as Remotely Operated Vehicle (ROV). ROV control design is one of the very interesting fields. The ROV design consists of many aspects: structural design [2,4], dynamic parameter identification [1], controller design [3] as well as experimental test and modification to suit the specified applications.

Jantapremjit [2] designed and built a small ROV that consists of pressure, compass, IMU sensors and CCD camera and can submerge upto 15 meter depth; as a result, underwater environment can be monitored. Kunchit and Prempraneerach [1] performed an estimation of ROV hydrodynamic coefficients by using a least-square technique so that added mass and damping parameters in surge, sway and heave motion can be accurately measured using a constant towing force. Suthakorn, Chuckpaiwong and Owatchaiyapong [4] developed "ThaiXPole" underwater robot to explore the Antarctica, so marine environment in an extreme condition can be explored and collected by scientists.

In this paper, Section 2 introduces ROV structural design and instrumental hardware that equips inside ROV. Experimental results, including thruster force measurement, pressure sensor measurement, software development for digital compass, and depth control using PID controller, are describes in Section 3.Lastly, Section 4 states conclusion and future work.

2. Design and Hardware

All structures and main instruments of ROV are designed within Solid Work, as shown in Fig. 1. Main criteria for this design are focus on compactness, drag reduction with cylindrical front, and neutral buoyancy when thrusters are at rest. Foam is added at the top of ROV structure to balance buoyancy as well as to increase floatation stability. Most of the ROV structures are built with Delrin, which is a corrosion resistance material and suitable to operate in both fresh and salt water. Fig. 2 shows a fully assembly of the ROV after performing a buoyancy balance so that this ROV is neutrally buoyant.

Overall specification for this ROV is given in Table 1. Four High Flow 400 HFS thrusters, used as main propulsion for this ROV, can operate underwater with a maximum depth of 50 meter and can produce maximum torque of 8 pound using 12-V power supply. These four thruster drives are Hydra-120 Castles. The first two thrusters are located horizontally at the back of ROV to provide thrust for a surge motion and a yaw moment, as shown in Fig. 2. The third thruster is installed in the vertical direction for a heave motion. The fourth thruster is attached perpendicular to the first two thrusters on the horizontal plane for a sway motion. Furthermore, these thrusters are operated by the Pulse Width Modulation (PWM) that generated from a 8-bit Arduino Mega 2560 microcontroller [6]. Also, pressure sensor and digital compass are connected to Arduino through analog and I^2C channels, respectively, such that ROV depth and orientation information can be measured. This information can help the operator to maneuver this ROV in water resources with high turbidity, like in river or reservoir. Main power source of this ROV is supplied by a 12-V deep-cycle battery. All electrical components receive their specified power from voltage regulators. Moreover, a small CMOS camera for underwater monitoring is installed inside a clear-acrylic cylindrical compartment at the ROV front. An instrumental connection diagram is shown in Fig. 3.

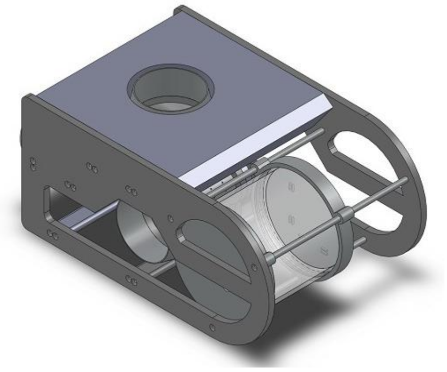

Fig. 1 ROV structural design within SolidWorks

Fig. 2 Fully assembled ROV

Table 1 Design specifications

Maximum Speed	1 m/s
Designated depth	10 m
Dimension (mm)	260x440x200
Weight	7.5 kg
Thrusters	4 High Flow 400 HFS thrusters
Sensors	Pressure sensor, Digital compass (HMC6343)
Battery	12 volt

3. Experimental Result

In this section, we divided into five topics that are composed of sensor and actuator calibrations, software development, depth control implementation, and ROV field test.

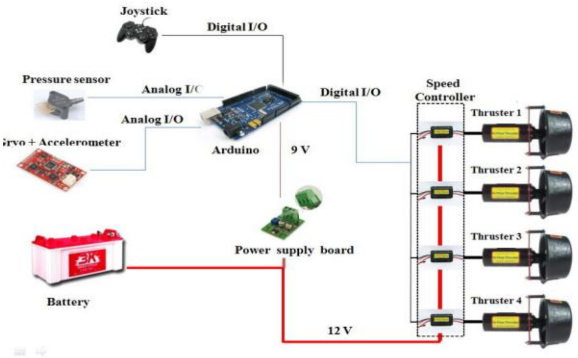

Fig. 3 ROV instrumentation diagram

3.1) Thrust force measurement

Thrust measurement is performed to obtained actuator force that can be used for control purpose and for basic understanding of thruster operation. The thrust force from the High Flow 400 HFS thrusters, with a 4.28:1 gear reduction, is measured by a three-axis force sensor for different PWM levels. According to axis coordinate in Fig. 4, positive and negative thrust force can be obtained from PWM signal with [1-1.5] millisecond or [0-50%] duty cycle and [1.5-2.0] millisecond or [50-100%] duty cycle, respectively. The operator can control thruster speed using an on-off push button connecting to Arduino, which is used to generate the PWM signal to Hydra 120 speed control. The experimental setup for thrust force measurement is shown in Fig. 4. The positive thrust force ($+F_y$) and negative thrust force ($-F_y$) with a constant PWM signal of 1.388 ms and of 1.611 ms from two experimental runs are displayed in Fig. 5 and 6, respectively, when the thruster starts from rest at 10 seconds. The thrust measurement shows that for different PWM level thrust force are maintained at constant level with a transient response less than 2 seconds.

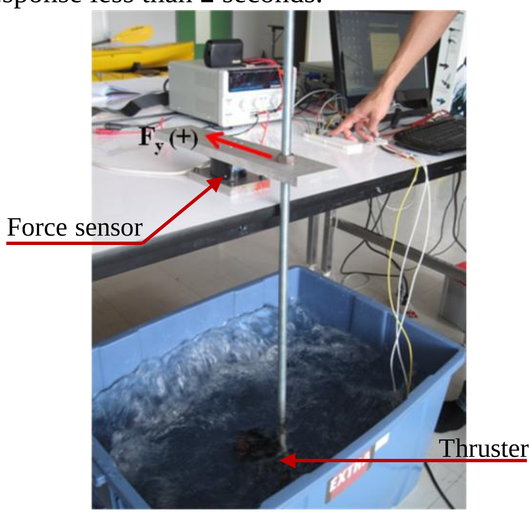

Fig.4 Experimental setup for thrust force measurement.

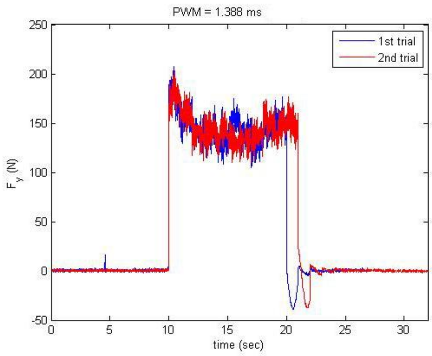

Fig.5 Thrust from High Flow 400 HFS thruster in positive direction with PWM = 1.388 ms

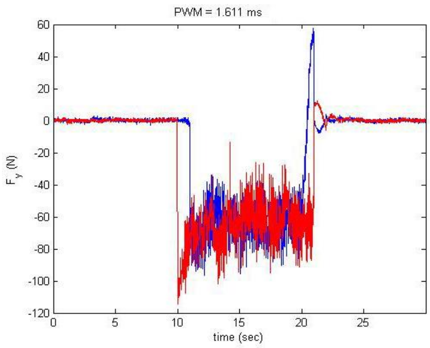

Fig.6 Thrust from High Flow 400 HFS thruster in negative direction with PWM = 1.611 ms

3.2) Pressure measurement

To calibrate MPX2010DP differential pressure transducer, the measurement must be collected at different water depth such that the relation between the sensor value and depth can be obtained. Relative pressure measurement is a difference between outside water pressure and inside seal acrylic cylinder. Signal from pressure sensor is amplified by a LM324 op-amp and then the analog signal is sent to Arduino Mega 2560 microcontroller. The experimental tests are done by submerging ROV down to different depth without turning on any thruster. The analog values from this pressure transducer are shown in Fig. 6 for three depths: 30, 40 and 90 cm. For each depth level, three measurements are taken to test a reliability of sensor reading. According to Fig. 7, in steady-state condition between 60-100 ms, all three measurements overlay on top of each other at different depth.

To convert the analog value from the pressure sensor reading to the water depth, a polynomial interpolation is used to fit the analog or real data using three different polynomial orders: 1st, 2nd and 3rd orders, as shown in Fig. 8. The 3rd order polynomial interpolation yield the best fit among the first three orders. Therefore, the water depth (d) can be calculated from the analog value (a) using the following formula:

$$d = 0.002a^3-0.996a^2+169.793a-9636.228 \qquad (1)$$

Using this pressure sensor, the conversion of the depth from the sensor reading is a nonlinear relation.

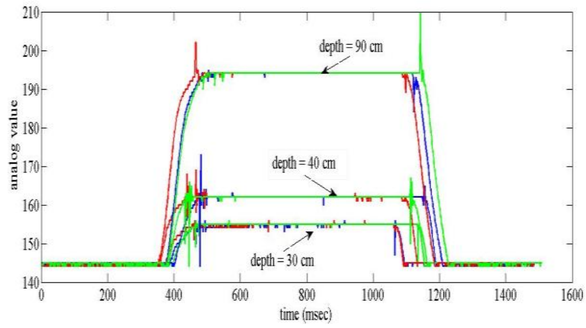

Fig.7 Pressure measurement for three depths : 30, 40 and 90 cm. Red, Blue and Green colors represent the first, second and third measurements.

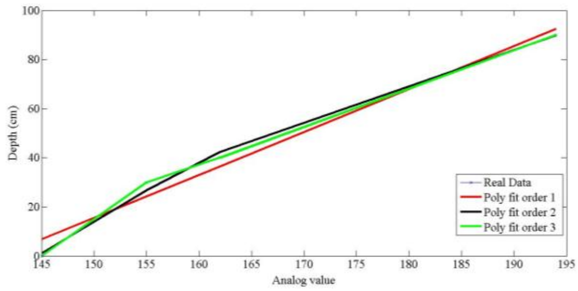

Fig.8 Data fitting using the polynomial interpolation with three different polynomial orders: 1st, 2nd and 3rd.

3.3) Digital Compass and Software Development

To obtain ROV orientation, 3-axis digital compass with tilt compensation (HMC6343) is used such that the operator can estimate ROV movement. Signal from digital compass transmit to Arduino microcontroller through I^2C, then sensor reading is transmitted to the processing program through RS-232. To easily visualize the information from this compass, the visualization software has been developed to show roll, pitch, and yaw (heading) angles using the processing program. Fig. 9 exhibits three dials for each rotation axis that vary between 0 to 360 degrees.

To test the operation of this visualization software, first the compass is set in the horizontal plane, as shown in Fig. 9, the yaw, pitch and roll angles are 90, 180 and 180 degrees, respectively. Second, the compass is rotated 90 degrees in both yaw and roll axes, as demonstrated in Fig. 10. From these tests, HMC6343 compass can provide accurate orientation with small angle errors.

Fig.9 Visualization software to show roll, pitch, and yaw angles of ROV, measured by digital compass.

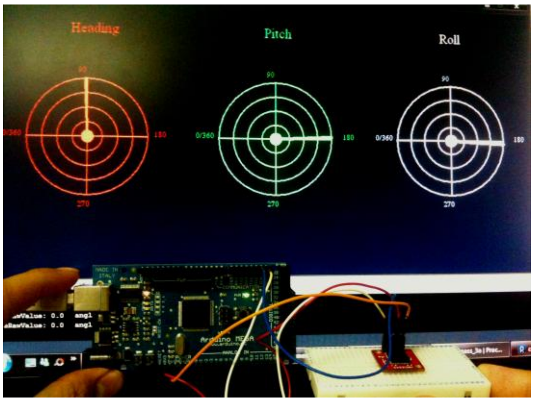

Fig.10 Initial position of the digital compass

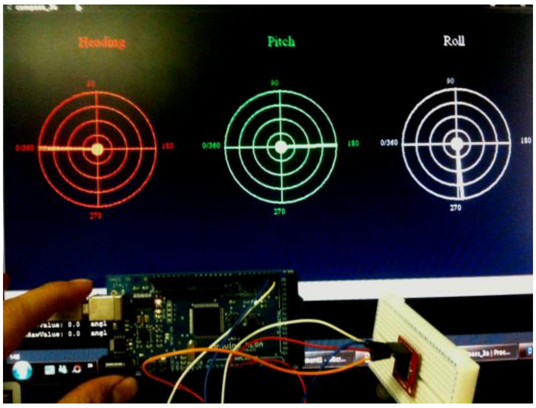

Fig.11 Digital compass rotates in both yaw and roll axes by 90 degrees

3.4) Depth Control using PID controller

A basic principle of PID controller is to minimize a feedback error to zero by tuning the proportional gain (K_p), derivative gain (K_d), and integral gain (K_i). A PID control law for a depth control is given by the following formula:

$$PWM = \left(K_p e + K_d \frac{de}{dt} + K_i \int e \, dt \right) + 1.5 \quad (2)$$

where the feedback error (e) is a difference between the depth command from user and the feedback signal from pressure sensor measurement. Output from PID controller is provided to the Castle thruster drive in a form of PWM command, thus 1.5 ms must be added to adjust a correct level. The block diagram of the closed-loop system using PID controller is shown in Fig. 12.

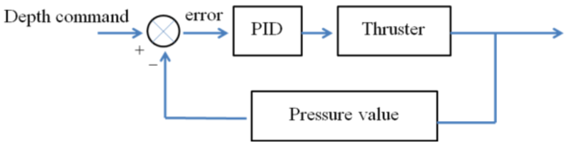

Fig. 12 Block diagram of the depth control using PID controller

The depth control using PID controller is implemented in the Arduino microcontroller [6]. The analog value of a desired depth, used as the depth command, is received from the joystick. With K_p = 1.5, K_d = 1 and K_i = 0.01, when the depth command is set to 163, corresponding to 40.9 cm depth, the feedback pressure value oscillates around 156, as shown in Fig. 13. The PWM thruster speed command is demonstrated in Fig. 14. These results reveal that the depth controller tries to maintain ROV at a constant depth of about 31 cm.

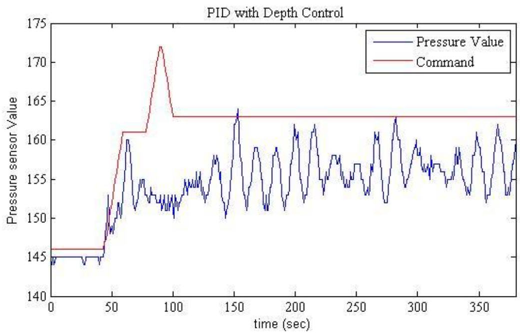

Fig.13 The depth command and the pressure sensor measurement

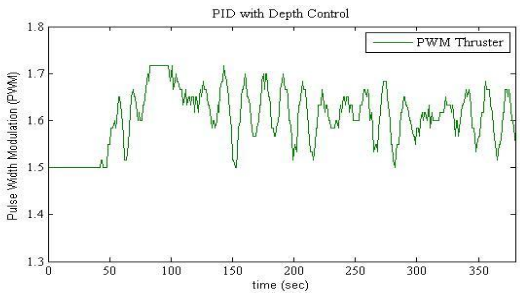

Fig.14 PWM command or the output from PID controller

3.5) ROV Field Test

Fig. 15 and 16 demonstrate the ROV operation in a swimming pool at Rajamangala University of Technology Thanyaburi (RMUTT). ROV speed is measured by timing the surge motion along a given straight path. The ROV speed that can be achieved with two thrusters operated at 10% duty cycle of PWM thruster command is approximately 1 m/s.

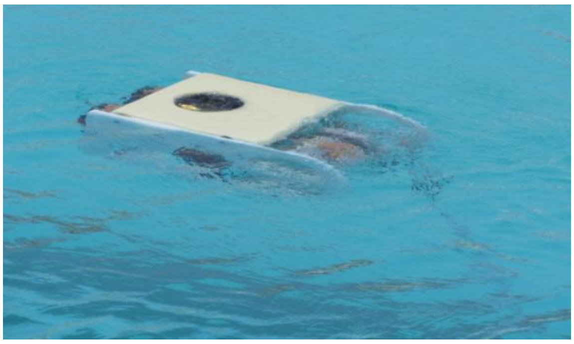

Fig. 15 Experimental test of ROV in RMUTT swimming pool.

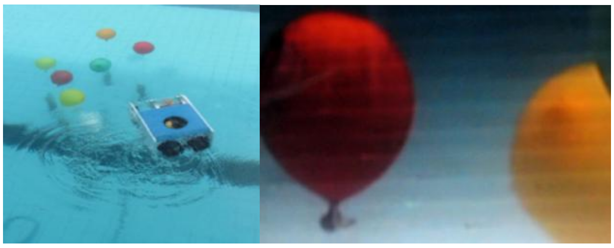

Fig. 16 Demonstration of search operation using color ballon in RMUTT swimming pool (Left) and video transmission from the CCD camera to computer screen (Right).

4. Conclusion

This research is focus on the design and construction of small ROV as well as the depth control using the Arduino microcontroller. Using the pressure sensor, ROV depth can be controlled and maintained at desired level. Moreover, the operator can visualize ROV orientation through the video camera and the visualization program using the signal from the digital compass.

5. Future Work

For additional improvements, tether communication must be upgraded to increase reliability in the data transmission and power source and power connection should be increase to achieve higher thrust force from all thrusters.

6. Acknowledgement

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7. References

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