Comparison of Depth Control from Surface and Bottom Set point of an Unmanned Underwater Remotely Operated Vehicle using PID Controller

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Abstract

This paper investigates the depth control of an Unmanned Underwater Remotely Operated Vehicle (ROV) based on ballast tank system using conventional PID controller. The PID Controller is applied to control the depth of the ROV from two different reference points, from the surface and from the seafloor. The concept of ballast tank system selected is piston tank type. Two different sensors are selected, which is pressure sensor for measurement from the surface, and sonar sensor for measurement from the bottom. Control method from both references point are investigated and compared to find out which feedback reference points are more appropriate in different conditions. The implementation phase will be verified through MATLAB Simulink platform. The verified algorithms will then be tested on the actual prototype ROV. And also the prospect of automated the vertical movement of a ROV.

Keywords: Depth control; Unmanned Underwater Remotely Operated Vehicle; Piston type Ballast tank system; PID controller

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1. Introduction

Unmanned Underwater Remotely Operated Vehicle (ROV) is essentially an underwater robot that is widely used in lot of underwater exploration such as industrial, marine study or work [1, 2]. As the name ROV implies, which means the movement control of such vehicles are fully controlled by human remotely, but different from controlling a vehicle on the road surface, underwater vehicles need to consider a lot more movement possibilities, especially vertical movement whereas this movement are label as the vehicle buoyancy [3, 4].

Buoyancy is the upward force exerted by the fluid on a body that is immersed [5, 6]. Buoyant force is the force different between large pressure pushing up under the object and the small force pushing down over the object. Based on the Archimedes Principle, magnitude of the upward force (buoyant force) of an object immersed in a fluid is equal to magnitude of weight of fluid displaced by object. Underwater vehicles will float or sink depended upon on the net effect of the weight of the object and the buoyant force generated by the object.

There are basically two methods to maintain the ROV at a certain depth, which is by using a propeller or by using a ballast tank [7]. Propeller method will react according to command and causes an additional downward or upward force to move the vehicle vertically without changing the vehicle's buoyancy [8, 9]. Whereas ballast tank method will changes the vehicle's buoyancy in order to move the vehicle. Propeller method has faster time response compared to ballast tank method but a constant power draw are needed as to maintain the vehicle depth, this will increase the difficulty for the operator to manage the vehicle's position and operation simultaneously [10]. Therefore ballast tank method are selected to reform the ROV into a semi-automated vehicle by replacing the vertical movement of a ROV with an automated ballast tank system to regulate the required depth set by the operator.

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2. Implementations

In order to achieve the objective, a few small experiments are done as shown in Fig. 1.

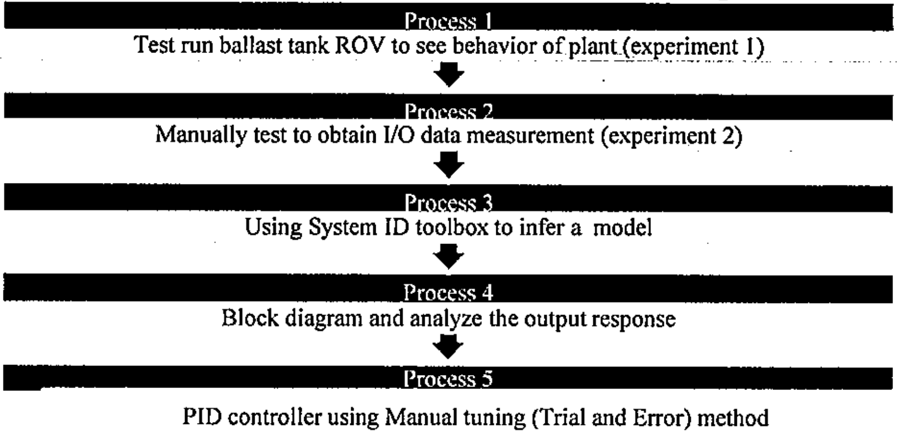
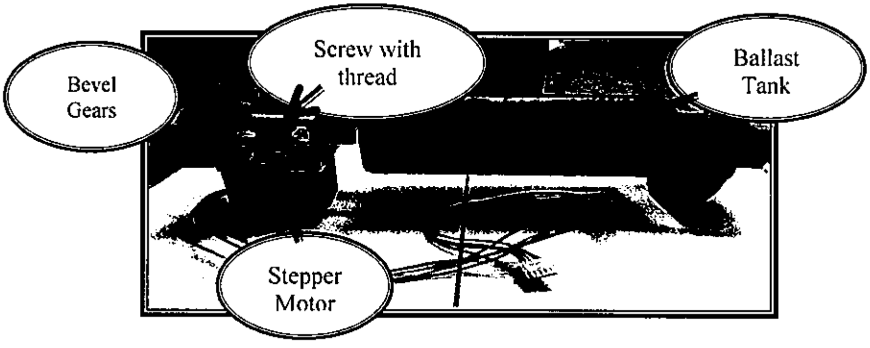


Fig. 1: Implementation Flow Chart

3. Piston Tank System

This prototype is only recommended for small or medium models, uses a modified Hand Air Pump which has bigger capacity compared to medical syringe whose capacity is about 20 to 60 cm^3. The holes at the piston are sealed and a rubber seal is attached to prevent water from seeping into the hull as shown in Fig. 2(a) and Fig. 2(b). The piston moves in the air pump body reduces the submarine buoyancy by sucking up in water. In doing so, the air is compressed inside the hull reducing the air volume. The piston is controlled by a stepper motor which is connected to the ballast tank via a bevel gear as shown in Fig. 2(c). Stepper motor is chosen because of precise and accurate movement control and has bigger torque to withstand outer pressure.

(a) Hand Air Pump (b) Piston Modifications



(c) Ballast Tank System

Fig. 2: Piston tank System

After the ballast tank has been constructed, a few tests are implemented to get the volume, weight, and depth capability of the ballast tank. The ballast tank system is put into a water tank and weights are increase until the ballast tank are slightly positive buoyancy and very near to neutral buoyancy. The piston is then moved manually so that the ballast tank can move up and down according to the piston movement that changes the systems buoyancy. This experiment is to find out the capability of the hardware, so that further testing will be done within that range. The picture of the ballast tank is shown in Fig. 3 and the characteristics of the ballast tank are shown in Table 1. Volume are measured by length and diameter of the Piston tank, weight are added until the top part of the ballast tank are floating just above the water line.

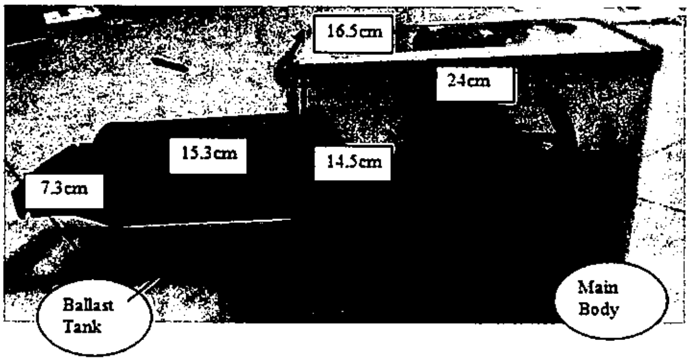


Fig. 3: Piston tank Hardware Prototype

Table 3: Characteristics of Prototype

Item	Characteristic
Volume of ballast tank(cm^3)	640.45 cm^3
Weight of the whole hardware at Neutral Buoyancy(kg)	30.23 kg
Maximum Depth that the hardware can go down and come back up	110cm

4. Sensors and Transfer Function

Two different sensors are then attached and data are collected to get the transfer function of the hardware. Distance from the surface are measured using pressure sensor as shown in Fig. 4 based on pressure cause by depth and distance from the bottom are measured using Sonar sensor as shown in Fig. 5 based on the distance to the seabed.

Fig. 4: Pressure Sensor

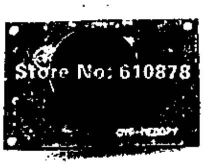


Fig. 5: Sonar Sensor

5. Results

All data are then fit into System Identifications is MATLAB Software and the transfer functions of the hardware are then determined [11]. On Model Order Selection, the second order was choose to get transfer function. After choose order type in Model Order Selection as shown in Fig. 6, back on System Identification Toolbox, click on Model Output to get the output performances for this system [12]. Fig. 7 shows the output for this model with best fit 71.65% which is the best that are gotten based on the handmade prototype hardware.

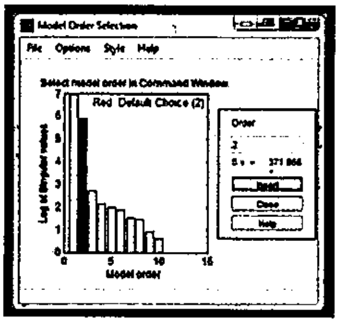


Fig. 6: Model Order Selection

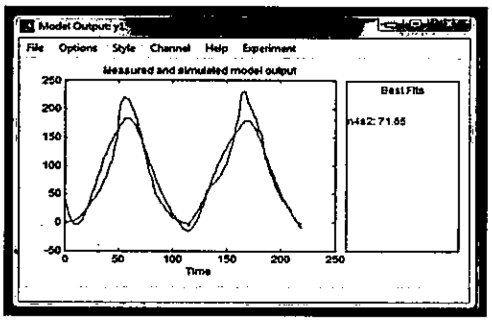


Fig. 7: Best fit Output Performance

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The transfer function obtained from System Identification is shown in equation 1

$$Tf = \frac{0.06818s + 0.9343}{s^2 + 5.971s + 12.5} \tag{1}$$

Once the Transfer Functions are gotten, both simulation and hardware test are done.

5.1 Simulation

PID controller is design to improve the output performance of the open loop system. The PID tuning method is used by manually tune value for Kp, Ki, and Kd until achieved desired performance. The priority that needs to be considered is overshoot, where output response must less than 6.5%. Next, priorities are rise time and settling time, where both must less than 2s. After that, this PID controller will be applied to real hardware to see the real performance (rise time and settling time) of the ballast tank prototype. PID controller is first tested in the Simulink block diagram as shown in the Fig. 8. Initially auto tune method is used to get the initial PID value range, then PID are then manually tune by trial and error to get a better responds as shown in Table 2 and the output response graph are shown in Fig. 9.

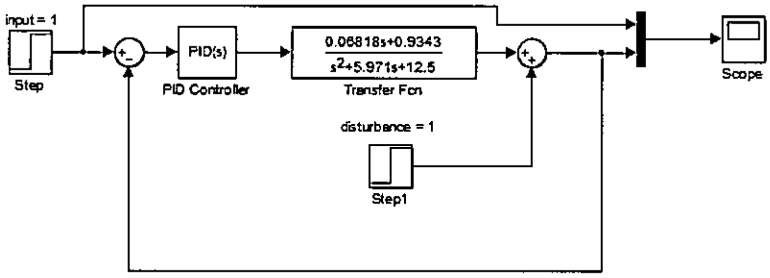

Fig. 8: Simulation Block Diagram

Table 1: Tuning Parameters

	Parameter of PID Controller					
Method	Kp	Ki	Kd	Rise time (seconds)	Settling time (seconds)	Overshoot (%)
Auto-Tuned	27.3	72.52	0	0.316	1.46	8.94
Trial and error Fine Tune P	0	72.52	0	0.365	8.95	57.7
	10.5	72.52	0	0.376	2.7	26.6
	28.87	72.52	0	0.37	1.43	8.2
	29.87	72.52	0	0.306	1.42	7.79
	31.87	72.52	0	0.299	1.41	7.07
Trial and error Fine Tune I	31.87	0	0	0.255	0.84	9.39
	31.87	30	0	0.454	3.54	0
	31.87	45.76	0	0.358	2.11	0
	31.87	58.77	0	0.332	1.56	2.49
	31.87	69.78	0	0.303	1.43	6.18
Trial and error Fine Tune D	31.87	69.78	1	0.35	1.4	2.84
	31.87	69.78	0.6	0.332	1.42	4.03
	31.87	69.78	0.58	0.331	1.42	4.1
	31.87	69.78	0.56	0.31	1.43	6.2

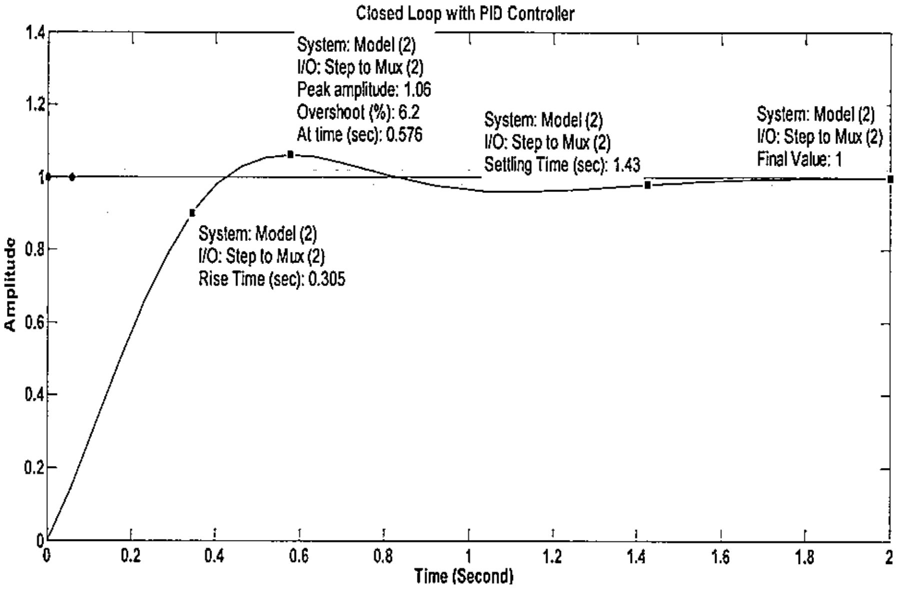

Fig. 9: Close Loop Output response

5.2 *Hardware*

When the PID value of Kp = 31.87; Ki = 69.78; Kd = 0.56 are applied to the hardware and test are done in an indoor tank by varying different distance from both the surface and bottom as shown in Fig. 10. Both main parameters considered are Rise time and Settling time. All results are shown in Table 3.

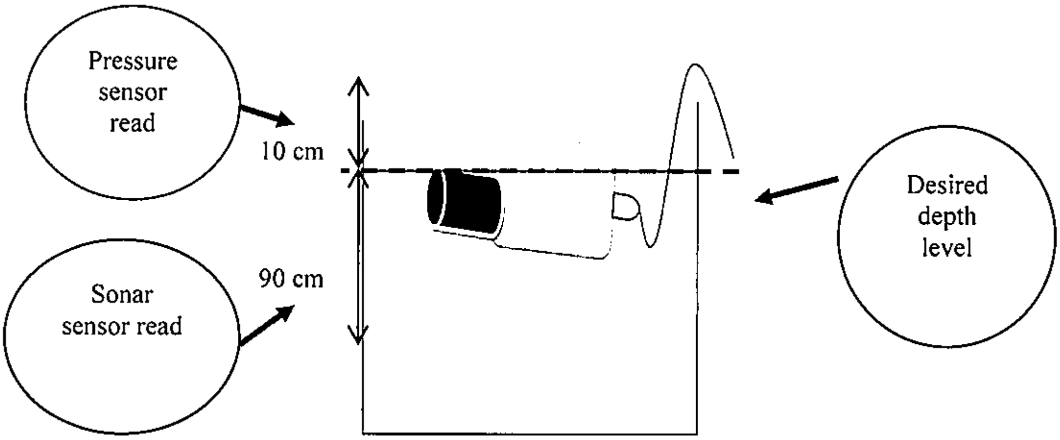

Fig. 10: Experiment Setup

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Table 1: Comparison Results of both sensor as feedback

Characteristic	**System control level from surface**	**System control level from bottom**
	Setpoint = Distance from Surface	**Setpoint = Distance from Bottom**
Type of sensor	Pressure sensor	Ultrasonic sensor
Closed-loop system (with PID controller)	➢ Setpoint = 10 cm	➢ Setpoint = 90 cm
	Tr = 80s, Ts = 88s	Tr = 239s, Ts = 269s
	➢ Setpoint = 20 cm	➢ Setpoint = 80 cm
	Tr = 147s, Ts = 155s	Tr = 126s, Ts = 224s
	➢ Setpoint = 30 cm	➢ Setpoint = 70 cm
	Tr = 96s, Ts = 151s	Tr = 120s, Ts = 195s
	➢ Setpoint = 40 cm	➢ Setpoint = 60 cm
	Tr = 82s, Ts = 119s	Tr = 35s, Ts = 55s
	➢ Setpoint = 50 cm	➢ Setpoint = 50 cm
	Tr = 73s, Ts = 146s	Tr = 13s, Ts = 40s

6. Conclusion

To summarise the results, it seems that the bigger the distance from the setpoint the bigger the rise time and settling time for both cases, from surface or from bottom. Therefore it is suggested that when designing feedback scheme, location depth aspects will play a big factor. And also if buoyancy level of ROV can be automated by setting a predefined distance first, then controlling ROV will be a lot easier.

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