DEVELOPMENT AND MODELLING OF UNMANNED UNDERWATER GLIDER USING THE SYSTEM IDENTIFICATION METHOD

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ABSTRACT

This paper describes a comparison study for the modelling of the unmanned Underwater Glider (UG) using system identification techniques based on two experimental set up. The experimental data obtained from lab tank test and pool test to infer model using a MATLAB System Identification toolbox. The experimental testing of UG only considered the horizontal movement or called as auto-heading. The modeling obtained will be used to design the suitable controller for heading control. The UG will be tested on an open loop system to obtain measured input-output signals. Input and output signals from the system are recorded and analyzed to infer a model using a System Identification MATLAB toolbox. Two models obtained based on data tabulated and verify using mathematical modelling of UG. The parameter of UG come up from the real model of UG and Solidworks software. The Underwater Lab Tank model has better performance which has faster rise time and settling time than swimming pool model and mathematical model.

KEYWORDS: *Underwater Glide; Auto heading control; System identification and mathematical modelling*

1.0 INTRODUCTION

Underwater Gliders (UGs) are in the family of the Autonomous Underwater Vehicle (AUV). UGs use the small change of its buoyancy in conjunction with wings to convert vertical motion into horizontal motion in order to propel themselves forward with very low energy consumption. Designing UG require deep knowledge on fundamental concept and theoretical background about the processes cum physical laws governing the underwater vehicle environment. There are two types of underwater vehicle namely manned underwater vehicles and unmanned undersea vehicles. Military submarines can be considered as

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a manned underwater vehicle. Remotely Operated Underwater Vehicle (ROV) and Autonomous Underwater Vehicle (AUV) are in the family of Unmanned Underwater Vehicles (UUV). Recently, studies on the speed and power consumption for UG performance as shown in Figure 1 and have been addressed in MSM Aras et al., 2011. The specification of UG designed by UTeRG Group tabulated in Table 1. More details of design and specification can refer (MSM Aras et al., 2011). Inspired by the slender-body theory in (M.F Sapee & MSM Aras, 2010, F.M Zain & MSM Aras, 2010). The USM Underwater Glider (USMUG) are modeled analytically, experimentally and computational technique. The techniques successfully model the glider with a low speed efficiency which is effective for internal moving mass (K. Isa & M.R Arshad, 2011). In (M.M Noh et al., 2011), the dynamic model and general kinematic for a longitudinal plane of USMUG are derived. The system is tested at 3 degrees of freedom basis and having a simple cylindrical shape with the nose cone shape. The auto heading is controlled by movable rudder and main wings.

There are three major types of underwater glider namely Slocum, Seaglider and Spray Glider. Slocum is a small gliding AUV of 40 000km operational range which harvest its propulsive energy from the heat flow between the vehicle engine and thermal gradient of the temperate and tropical ocean (Webb et al., 2001). Slocum produces energy from the heat flow of its own engine and the thermal inclination of the ocean. The two types Slocum glider is an electric powered glider and thermally powered. The electrical powered Slocum operates at 200 meters depth at speed of 0.5 m/s using a syringe type ballast pump. It is 1.8 meters long with a hull of 1.5 meters, 54 cm in diameter and tail of 0.3 meters long. The syringe type ballast pump has a 500 cc volume capacity that stated at directly behind the nose of the glider. It is controlled by moving a battery pack located in the front section of the hull. Slocum has fixed wings with one meter span and swept in order to avoid fouling by seaweed. Wings are designed with the flat plats to lessen the drag. Slocum also has a vertical tail with rudder. It has an antenna for GPS and communication (Isa & Arshad, 2011). Seaglider is a product of collaboration between APL-UW School of Oceanography. This small freewheeling vehicle can collect conductivity-thermal-depth data from the ocean for months at a time and transmit it to the shore of a real-time data via satellite. Seaglider makes the conventional data gathering and measurement easier and faster but with the fraction of the cost. It can review along transect, profile at a fixed location and can instructed to change its course. Seaglider has a range of roughly 6000km operation depth. It is 52 kg and its hull is made from an internal pressure hull and an external fairing. The fairing is 1.8 m long with a 30 cm maximum diameter and is free flooding. Seaglider is designed to dive as deep as 1500m. The Seaglider external fairing uses a different design than other gliders. The shape is derived from a low drag laminar flow shape used by the Navy in target drones. The shape is designed to reduce pressure drag by developing a favorable pressure gradient at the rear of the vehicle. Seaglider has a fixed wing with one meter span and vertical tail fins situated above and below the body. The location of Seaglider's wings is near the rear of the vehicle causes a reversal of a coupling between roll and yew. Seagliders fly through the water with extremely modest energy requirements using changes in buoyancy for thrust coupled with a stable, low-drag, hydrodynamic shape. The hull compresses as it sinks, matching the compressibility of seawater. Spray glider is a small underwater vehicle with a weight of 50kg and a length of 2 meters that operates at a speed of 20-30 cm/s and ranges up to 6000 km has been developed and field tested. The vehicle is essentially an autonomous profiling floats that uses a buoyancy engine to cycle vertically and wings glide horizontally while moving up and down. The spray is named after Slocum's ship that Joshua Slocum rebuilt and piloted around the world. It is cheap enough to be used in a large number. The spray has a range of thousands of kilometers, depending on speed, sensing, communications and other energy use. It also uses lithium battery, which has a greater energy density and performance than an alkaline battery. The spray has a cylindrical pressure hull with two wings and vertical tail. The rear of a hull housed an oil-filled bladder for the ballast system. This design makes the pump more suitable to be used in a glider by allowing it to operate in different orientation and avoid losing the pump. The Spray design uses two internal moving masses, one for pitch and one for roll. That makes it different with Slocum and Seaglider which it moves in single battery packed. The roll actuator is a battery pack located in the nose of the vehicle and can rotate 360 degrees. The pitch actuator is a battery pack moved by a rack and a pin actuation system driven by DC motors. The spray's antenna is located inside of the wings, and the vehicle rolls on its side to extend this wing above the surface for GPS and Orbcomm communication. The wing aerodynamic center is located behind the vehicle CG, placing the vehicle center of lift 10cm behind the CG and CB for stability.

The purpose of this research is to model the underwater gliders using system identification method. Past research on system identification approach can be reviewed in (Rozali & Kamarudin, 2010, A. Khamis et al., 2010; D. Hanafi et al., 2009; MSM Aras et al., 2013). The system identification process offers less complex mathematical derivation and worthwhile for controller design phase. Through system identification process, all important information such as the best fit, residual analysis, correlation, and pole-zero location of the system are obtained. Few structures of parametric model such as ARX model, Auto-Regressive Moving Average with Exogenous Input (ARMAX) model, output-error (OE) model and Box-Jenkins (BJ) model can be used as underwater glider. ARX model serves the basic structure as this structure ignores the moving average or the error dynamics of the system. In (Rozali & Kamarudin, 2010) and (A. Khamis et al., 2010), the ARX model is used for liquid level model and DC-DC boost converter respectively. In (D. Hanafi et al., 2009), a quarter car passive suspension systems are formulated in NARX structure which is based on iterative weighted least square neural network. In (MSM Aras et al., 2013a) and (MSM Aras et al., 2013b) system identification used to modeling ROV and thruster. Motivated by these, new approach for underwater glider modeling will be discussed thoroughly via system identification and simulation works are presented to verify the modeling results.

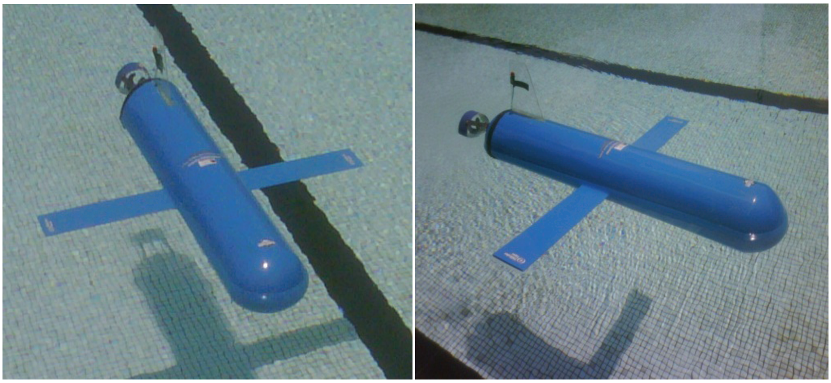


Figure 1. The glider in the pool from front and side view

Table 1. UTeRG GLIDER Specification

Item	Specification
Manufactured	Mechatronic Engineering
Platform	UTeRG GLIDER
Body Type	Torpedo + Wing
Size (L x W x H)	(106cm x 90cm x 20cm)
Hull Material	Fiberglass
Weight	14kg
Dynamic Buoyancy	Not Tested
Obstacle Avoidance	No
Color	Blue

2.0 METHODOLOGY

The movement of this Underwater Glider was focused on auto-heading control which means that the UG glides on the surface of water only. The circuit and programming were already made by previous research that doing a project about the designing of Underwater Glider (Aras et al., 2011; Sapee & Aras, 2010; Zain & Aras, 2010). To achieve the objective, the circuit and programming were studied and the new movement was programmed on that circuit because the previous movement of Underwater Glider was programmed for three degrees of freedom. The movement of Underwater Glider was controlled by Microprocessor PIC because it was easy to implement. The new movement of Underwater Glider was successfully programmed, the existed Underwater Glider has been integrating. Next, the function of an Underwater Glider with the new programming will be tested. This part was important in order to make sure the Underwater Glider can function well with its new program. The modeling of Underwater Glider by using an experimental technique was done when there is no problem with the functional test. In this experimental part, the test of the auto heading Underwater Glider was done in order to get the input, output and data. The auto heading test was done at the lab tank and look at length within 10m. For the experimental part that was done at the lake, the Underwater Glider was set to 10m meanwhile the experimental part that was done on the lab tank was set to 5.5m. For both experimental parts, the time for Underwater Glider reach final destination was recorded.

From the data that was recorded, the speed was measured by distance over time. The manual method was used in order to write down the data from the auto heading test. The data from experimental part of the lake and the lab tank was collected towards 401 and 221 of data. There are some influential factors that affect the result. The error was caused by the wave formed on Lab tank and the lake. That wave makes the glider wobbling. The wobbling of Underwater Glider on surface of water will affect the result. After the experimental technique, all the data were collected. Then, System Identification in MATLAB Toolbox was used in order to infer a model of UG.

Next, the simulation model of Underwater Glider was successfully done using Solidworks software. The software model of Underwater Glider was compared with the model of the mathematical technique. This part was verified either the model of this Underwater Glider that using an experimental technique slightly different or the same with the mathematical technique (MZ Ab Rashid & SN Sidek; 2011; MZA Rashid et al., 2012). The project process flow was successful when the Unmanned Underwater Glider has been modelled by experimental technique using System Identification in MATLAB Toolbox and it was verified with the mathematical technique. Figure 2 shows the overall methodology.

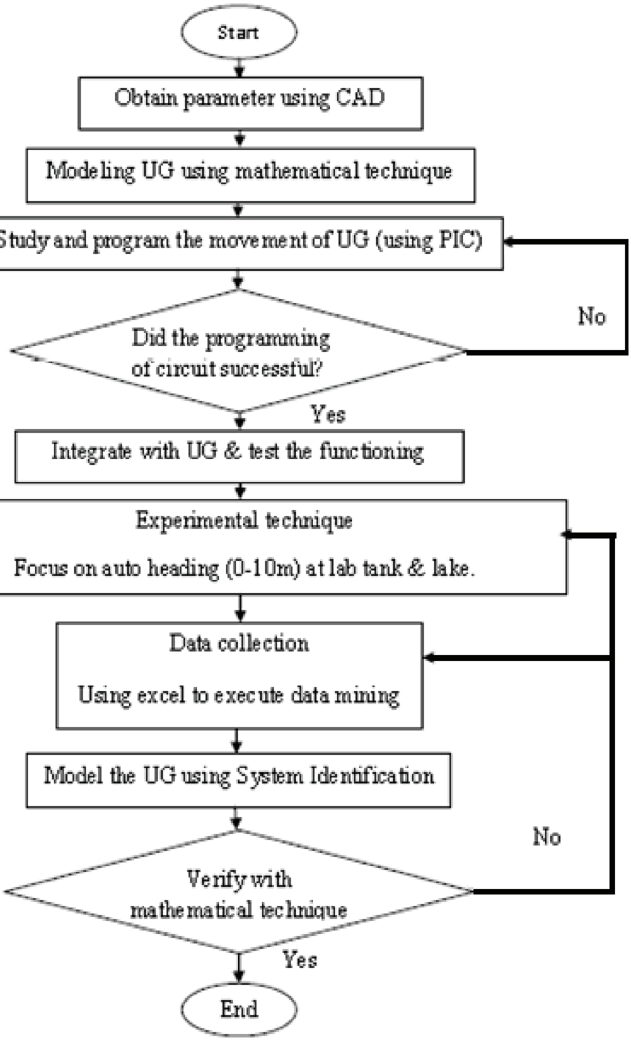


Figure 2. Methodology of this project

2.1 Modeling of Underwater Glider using mathematical techniques

These sections explain about the method that used in order to achieve the objective of this project. The objective of this project is to model Underwater Glider using mathematical techniques. The dynamics of a 6-degree-of-freedom underwater vehicle can be described in the following general form as Equation (1) (T.I. Fossen, 1994 & MSM Aras et al., 2009):

$$m\dot{v} + C(v)v + D(v)v + g(\eta) = B(v)u \tag{1}$$

where,

m is the 6 x 6 inertia matrix including hydrodynamic added mass.
$C(v)$ is the Matrix of Coriolis and centripetal forces.
$D(v)$ is the Hydrodynamic damping matrix.
$g(\eta)$ is the Vector of restoring forces and moments.
$B(v)$ is the 6 x 3 control matrix.

By assuming decoupling between the degrees of freedom, that is, assuming that motion along or about one degree of freedom does not affect another degree of freedom, the dynamic model of an UG can be significantly simplified (MSM Aras et al., 2012). The decoupling means that the Coriolis and centripetal terms matrices become negligible and consequently can be eliminated from the dynamic model (F. A. Azis et al., 2012). The simplified dynamic model for the UG then becomes,

$$m\dot{v} + D(v)v + g(\eta) = B(v)u \tag{2}$$

2.1.1 *Mass and Inertia Matrix*

The frame was positioned at the center of gravity. The equation MRB was simplified to a good approximation to Equation 3. The basic equation of modeling of the UG (for Equation 3,5,7 and 9) derives and simplified from L.A. Gonzalez, 2007. The parameter of UG based on Equation 2,4,6 and 10 obtained from MSM Aras et al., 2011.

$$M_{RB} = \begin{bmatrix} m & 0 & 0 & 0 & 0 & 0 \\ 0 & m & 0 & 0 & 0 & 0 \\ 0 & 0 & m & 0 & 0 & 0 \\ 0 & 0 & 0 & I_x & -I_{xy} & 0 \\ 0 & 0 & 0 & -I_{xy} & I_y & 0 \\ 0 & 0 & 0 & -I_{xz} & -I_{yz} & I_z \end{bmatrix} \tag{3}$$

In the equation 1, the mass of underwater glider and all parameters that had obtained from the mass properties SolidWorks were inserted. The value of the mass of the glider that submerges 70% underwater is equal to 22.7 kg. Therefore, at x axis, y-axis and z axis, the parameter of mass was inserted is 22.7 kg. The value on y-axis and x-axis also been inserted into the matrix even though the limitation of this project was focused on auto heading movement or on x axis only. This is because, on a surface of water, the y-axis and z axis also give effect to the glider by its buoyancy. Therefore, the value of the parameter from SolidWorks like = 0.242, = 0.269 and 18.53 were inserted into the matrix in equation 4. After all the parameter that required already inserted, the matrix became like equation 4.

$$M_{RB} = \begin{bmatrix} 22.7 & 0 & 0 & 0 & 0 & 0 \\ 0 & 22.7 & 0 & 0 & 0 & 0 \\ 0 & 0 & 22.7 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0.242 & -1.6e\text{-}04 & -0.1850 \\ 0 & 0 & 0 & -1.6e\text{-}04 & 0.269 & 6e\text{-}04 \\ 0 & 0 & 0 & -0.1850 & 6e\text{-}04 & 18.53 \end{bmatrix}$$

(4)

The added mass matrix, becomes as Equation 5 below after been simplified as alike Equation 4.

$$M_A = \begin{bmatrix} X_{\dot{u}} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & Z_{\dot{w}} & 0 & 0 & 0 \\ 0 & 0 & 0 & N_{\dot{p}} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

(5)

For Underwater vehicle, the normal value is 54.7, while the value for is 1.0295e $^{+03}$. The matrix of Equation 5 become as Equation 6 after the value of X_u and Z_w was inserted.

$$M_A = \begin{bmatrix} 54.7 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1.029e+03 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

(6)

2.1.2 *Hydrodynamic Damping Matrix*

The equation of a hydrodynamic damping matrix, D (V) listed as in Equation 7.

$$D(V) = \begin{bmatrix} X_u + X_{u|u|}|u| & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & Z_w + Z_{w|w|}|w| & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & N_r + N_{r|r|}|r| \end{bmatrix}$$

(7)

Then, the hydrodynamic damping matrix, D (V), simplifies to equation 7 after the value of $X_u + X_{u|u|}\ |u|$ which equal to 77.4 was inserted.

$$D(V) = \begin{bmatrix} 77.4 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \tag{8}$$

The value of $N_r + N_{r|r|}\ |r|$ and $Z_w + Z_{w|w|}\ |w|$ was assumed to zero when the limitation of this project was focused on auto heading only.

2.1.3 Gravitational and Buoyancy Vector

For the gravitational and buoyancy vector, the weight of the glider is 222.46N while the buoyancy force is 318.463N.

$$G = \begin{bmatrix} X \\ Y \\ Z \\ 0 \\ 0 \\ 0 \end{bmatrix} \tag{9}$$

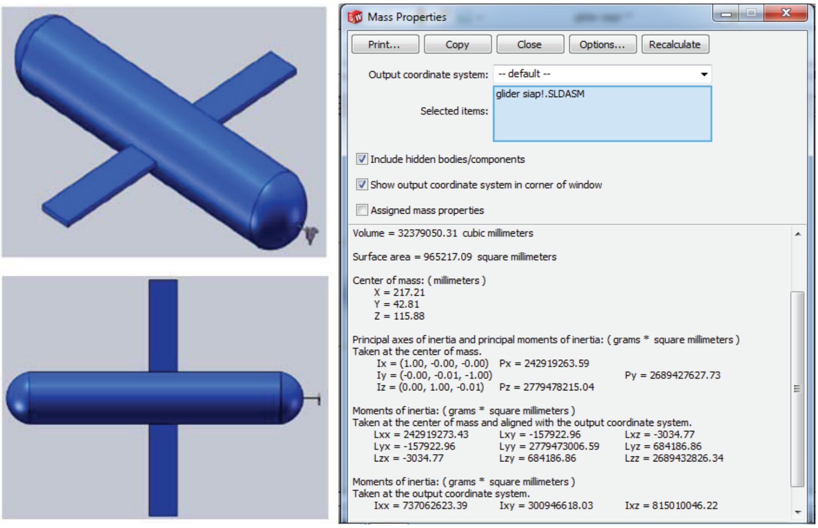
Since, the limitation of this project just focuses on auto heading movement, therefore, the value of y and z axis assumes as zero. The final matrix of gravitational as shown in Equation 10.

$$G = \begin{bmatrix} 96 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} \tag{10}$$

The value of 96N implies that the vehicle has residual buoyancy just as it was designed to have. The residual buoyancy equates to 70% of the vehicle's weight. Equation 10 shows that the gravitational and buoyant forces of the vehicle only affect the heave of the vehicle. This is expected given that the centers of gravity and buoyancy are aligned along the x and y axes, and hence, the gravitational and buoyant forces should then only affect vertical movement.

3.0 RESULTS AND DISCUSSION

The result obtains will be used as material for analysis and how the result achieved and possibility for improvement. The theory behind the result obtained complying with the hardware functionality resultant the desired result. Each of the results of the analysis is discussed. The Figure 3 shows the mass properties of the glider in the SolidWorks. From this mass properties window, the mass, volume, surface area and moment of inertia can be determined. From the mass properties, the value that equal to 0.242, value that equates to 0.269 and value that's equal to 0.278 was used in the mathematical modeling.



Output coordinate system: -- default --

Selected items: glider siap!.SLDASM

☑ Include hidden bodies/components

☑ Show output coordinate system in corner of window

☐ Assigned mass properties

```
Volume = 32379050.31  cubic millimeters

Surface area = 965217.09  square millimeters

Center of mass: ( millimeters )
	X = 217.21
	Y = 42.81
	Z = 115.88

Principal axes of inertia and principal moments of inertia: ( grams *  square millimeters )
Taken at the center of mass.
	 Ix = (1.00, -0.00, -0.00)   Px = 242919263.59
	 Iy = (-0.00, -0.01, -1.00)                            Py = 2689427627.73
	 Iz = (0.00, 1.00, -0.01)    Pz = 2779478215.04

Moments of inertia: ( grams *  square millimeters )
Taken at the center of mass and aligned with the output coordinate system.
	Lxx = 242919273.43          Lxy = -157922.96           Lxz = -3034.77
	Lyx = -157922.96            Lyy = 2779473006.59        Lyz = 684186.86
	Lzx = -3034.77              Lzy = 684186.86            Lzz = 2689432826.34

Moments of inertia: ( grams *  square millimeters )
Taken at the output coordinate system.
	Ixx = 737062623.39          Ixy = 300946618.03         Ixz = 815010046.22
```

Figure 3. Mass properties of Underwater Glider

3.1 Mathematical Modeling Technique

The objective of this project is to model Underwater Glider using System Identification but to validate the results of system identification techniques the mathematical techniques will be used. Figure 4 shows the mathematical modeling of Underwater Glider. All parameters that were obtained from SolidWorks and mathematical equation was inserted into the model. The P and I controller was set each manually to 4.5. Next, the simulation was run and the graph from scope was obtained as in Figure 5. From the graph, it shows that the plant had been controlled by PI controller.

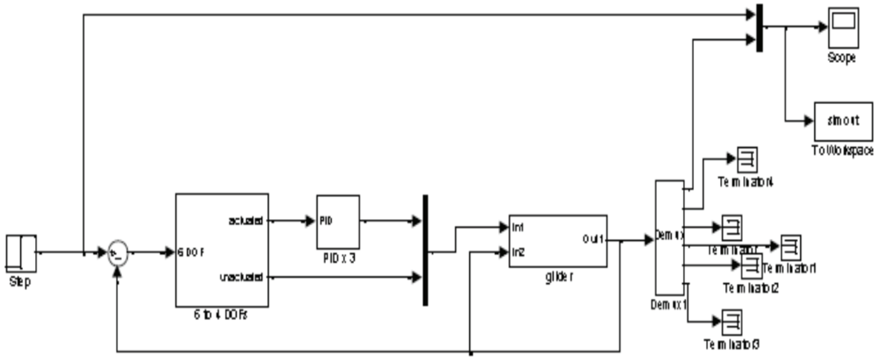


Figure 4. Simulation for mathematical modeling of underwater Glider

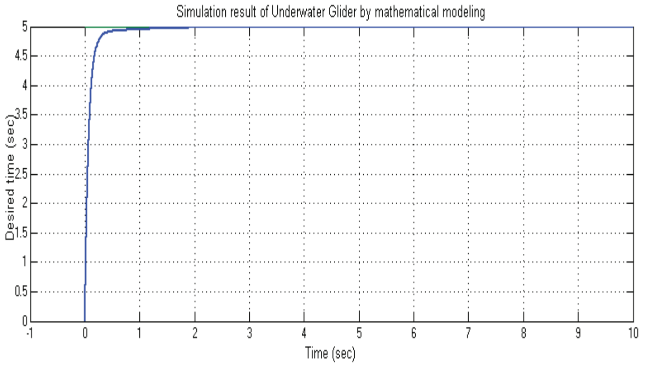


Figure 5. Simulation result of Underwater Glider by mathematical modeling

3.2 System Identification

3.2.1 Underwater Lab Tank

In this section, the data that were collected in the experiment was imported into the system Identification. The step of system identification was following the manual lab for Control System Design with real time implementation using Microbox and can be referred (MSM Aras et al., 2013 & M. N. Taib et al., 2007). The best fits that were obtained from system identification is 93.97 as shown in Figure 6.

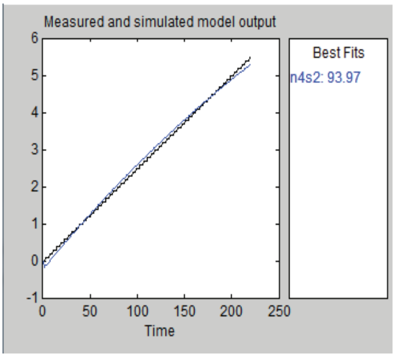


Figure 6. Best fit for Lab Tank

The transfer function that was obtained from this plant is as shown in equation 11. Next, the transfer function that was successfully obtained was inserted into the control system using a P controller to gain equal to 1 as shown in Figure 7.

$$TF = \frac{-8.03s^2 - 7.602 \times 10^3 s + 1.083 \times 10^8}{s^3 + 4123s^2 + 1.412 \times 10^7 s + 2.89 \times 10^7} \tag{11}$$

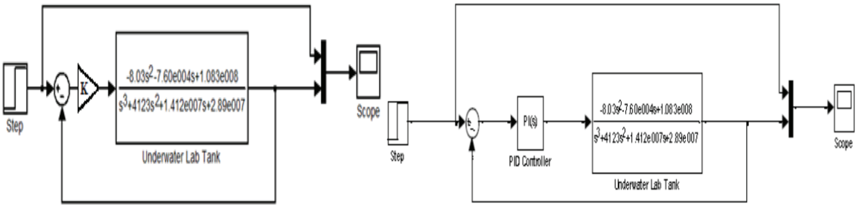


Figure 7. Control System for Model of Underwater Glider using System Identification

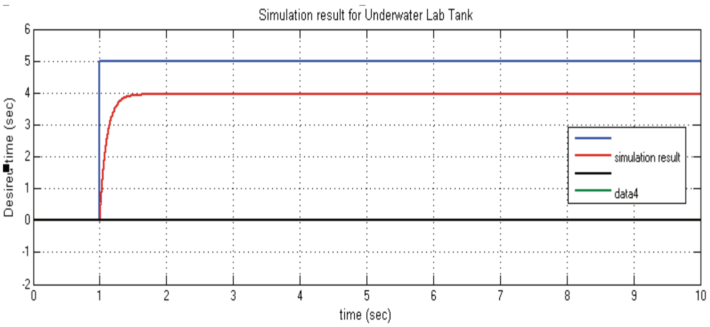


Figure 8. Simulation result of Underwater Lab Tank with P controller

The model was run for 10 seconds and the simulation result for the model was shown in Figure 8. The Figure 8 shows that the respondent of the plant cannot reach the input data of the plant. Therefore, the PI controller was needed in order to improve the simulation result and it can reach the input data. The block of PI controller was added into the plant model. The model was run for 10 seconds and the output response of the simulation was shown in Figure 9.

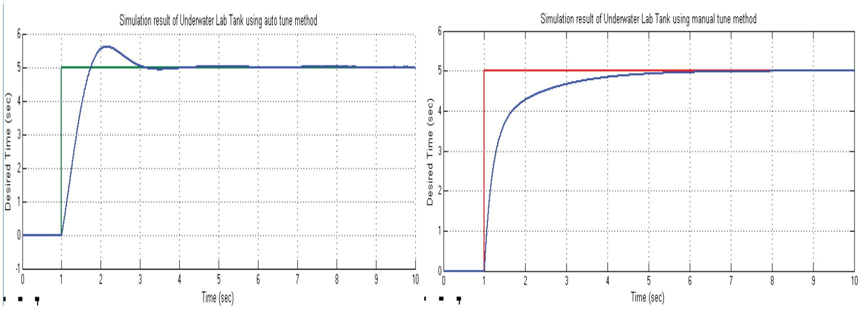


Figure 9. Simulation result of Underwater Lab Tank using auto and manual tune method

The auto tune method was used in order to obtain the best graph. By using auto tune method, the P controller was set as 0.16695 meanwhile I controller were set to 1.0702. The auto tune method gives a rise time in 0.55 seconds and settling time in 1.89 seconds. However, in Figure 9, the simulation graph shows that the auto tunes method has 12.2% of overshoot. In order to reduce or eliminate the overshoot, the PI controller needs to tune manually.At first, the P and I was tuning manually by inserting the value of each of them as 0.5. Figure 9 shows the simulation result of Underwater Lab Tank by tuning the P and I controller 0.5 each. The rise time for this simulation is 1.43 seconds, the settling time of this simulation is 3.61 seconds and meanwhile the overshoot for this simulation is 0%.

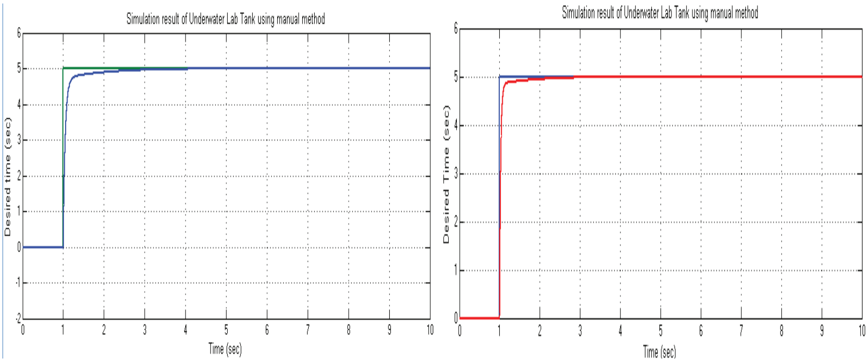


Figure 10. Simulation result of Underwater Lab Tank with fixed value of parameter controller

Figure 10 shows the simulation result of Underwater Lab Tank when its P and I controller was tuned as 2.5 and 4.5 each, respectively. The rise time for this simulation is 0.136 s and 0.0679 s, the settling time of this simulation is 1.11 s and 0.448 s respectively meanwhile the overshoot for this simulation is 0% for both gain.

Table 2. Comparison between each PI controller

P	0.5	2.5	4.5
I	0.5	2.5	4.5
Rise Time (s)	1.43	0.136	0.0679
Settling Time (s)	3.61	1.11	0.448
Overshoot (%)	0	0	0

Table 2 shows the comparison of the P and I controller when tune manually in different value. From the table, it shows that the overshoot of each controller is 0% . However, the rise time and settling time for value of P and I was set to 4.5 is 0.0679s and 0.448s which much faster than the other controller. Therefore, the P and I controller for this model tune to 4.5.

3.2.2 *Swimming pool*

In this section, the data that were collected in the experiment was imported into System Identification. The step of System Identification was following the manual lab for Control System Design with Real Time Implementation using EMECS Micro-Box. The best Fits that were obtained from system Identification is 92.14 as shown in Figure 11.

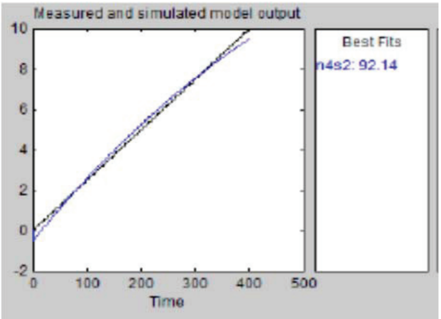


Figure 11. Best fit for swimming pool

The transfer function that was obtained from this plant is as shown in Equation 12.

$$TF = \frac{-26.84s+1.849\times10^4}{s^2+4813s+7331} \tag{12}$$

Next, the transfer function that was successfully obtained was inserted into the model as shown in Figure 12.

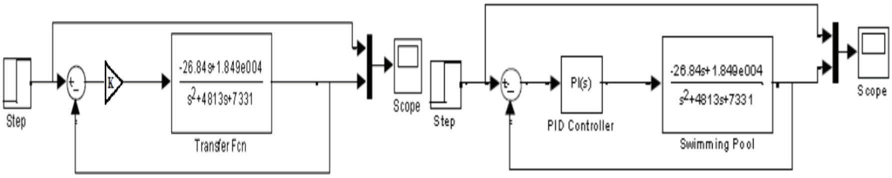


Figure 12. Model for swimming pool

The model was run for 10 seconds and the simulation result for the model was shown in Figure 13. The Figure 13 shows that the system response of the plant cannot reach the input data of the plant. Therefore, the PI controller was needed in order to improve the simulation result and it can reach the input data.

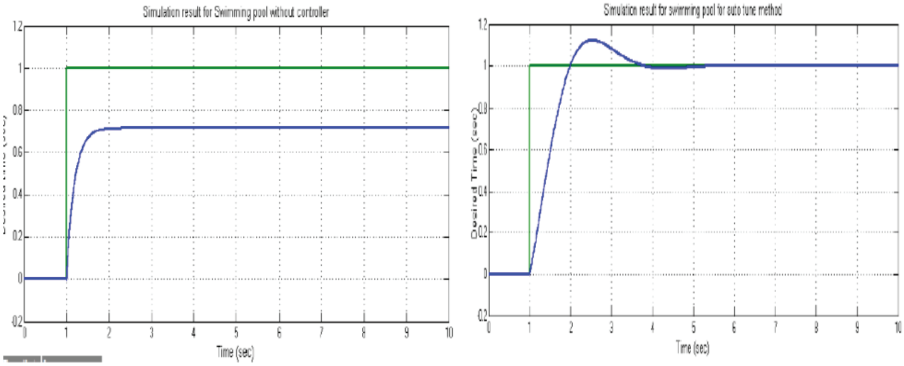


Figure 13. Simulation result for Swimming pool with P controller

Figure 14 shows that the block of PI controller was added into the plant model. The model was run for 10 seconds and the output response of the simulation was shown in Figure 14. The auto tune method was used in order to obtain the best graph. By using auto tune method, the P controller was set as 0.2522 meanwhile I controller were set to 1.1969 as shown in Figure 14. The auto tune method gives a rise time in 0.733 seconds and settling time in 2.52 seconds. However, in Figure

14, the simulation graph shows that the auto tunes method has 12.2% of overshoot. In order to reduce or eliminate the overshoot, the PI controller needs to tune manually.

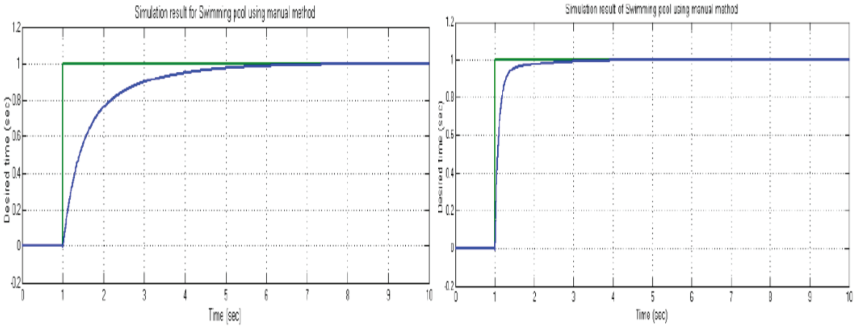


Figure 14. Simulation result of swimming pool using manual methods

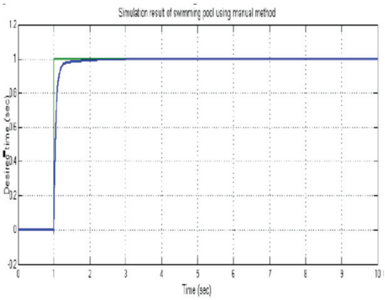


Figure 15. Simulation result of swimming pool using manual methods

At first, the P and I was tuning manually by inserting the value of each of them as 0.5. Figure 15 shows the simulation result of Underwater Lab Tank by tuning the P and I controller 0.5 each. The rise time for this simulation is 1.96 seconds, the settling time of this simulation is 4.29 seconds and meanwhile the overshoot for this simulation is 0%. Figure 15 shows the simulation result of Underwater Lab Tank when its P and I controller was tuned as 2.5 each. The rise time for this simulation is 0.269 seconds, the settling time of this simulation is 1.2 seconds and meanwhile the overshoot for this simulation is 0%. Figure 15 shows the simulation result of Underwater Lab Tank when its P and I controller was tuned as 4.5 each. The rise time for this simulation is 0.0136 seconds, the settling time of this simulation is 0.498 seconds and meanwhile the overshoot for this simulation is 0%.

Table 3. Comparison between each PI controller

P	0.5	2.5	4.5
I	0.5	2.5	4.5
Rise Time (s)	1.96	0.7	0.14
Settling Time (s)	4.29	1.2	0.49
Overshoot (%)	0	0	0

Table 3 shows the comparison of the P and I controller when tune manually in different value. From the table, it shows that the overshoot of each controller is 0% . However, the rise time and settling time for value of P and I was set to 4.5 is 0.136 s and 0.498s which much faster than other controller. Therefore, the P and I controller for this model tune to 4.5.

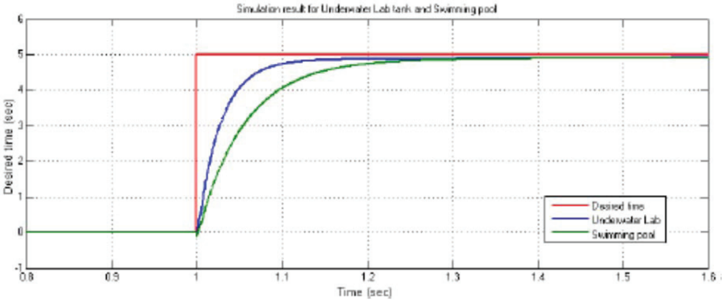


Figure 16. Simulation result of Underwater Lab tank and swimming pool

Figure 16 shows the simulation result that was obtained from the model for Underwater Lab Tank and swimming pool. From the Figure, it shows that the Underwater Lab Tank model which is in green color have a better response than the swimming pool simulation result which is in red color. It may be because of the rise time of Underwater Lab Tank has faster rise time which is 0.0679 seconds than the swimming pool model which have 0.136 seconds. The Underwater Lab Tank also has faster settling time which is 0.448 second than swimming pool which is 0.498 seconds. For this section, it can conclude that the Underwater Lab Tank model has better performance than the swimming pool model.

3.2.3 *Verification of model*

In this section, the model from mathematical was verified with model from system identification as in Figure 17. The entire PI controller was a manual tune of 4.5. The graph that obtained from the scope was compared.

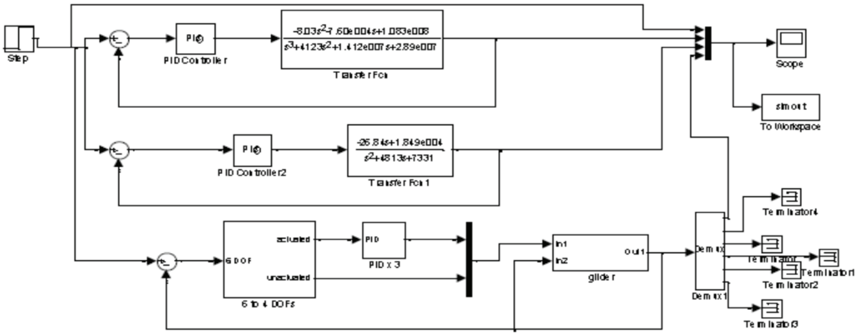


Figure 17. Simulation for verification of underwater glider modeling

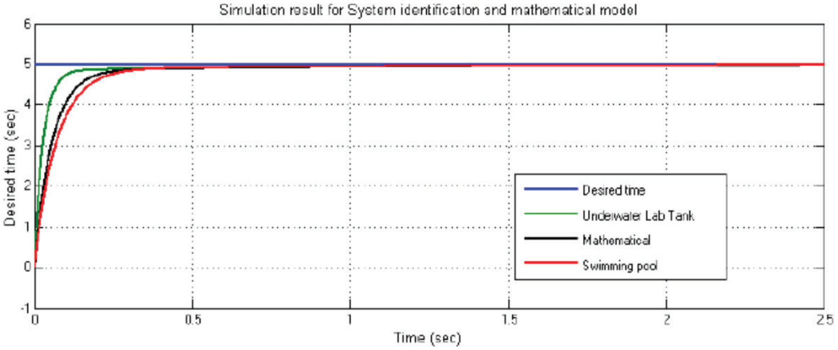


Figure 18. Simulation result for system identification model and mathematical model

Figure 18 shows the simulation result for system identification model and mathematical model. From the Figure 18, it shows that the model of Underwater Lab Tank which in green color has better performance than the mathematical model which in black color and swimming pool model which in red color. From the theory, the mathematical model should have better performance than others. However, in this project the response of mathematical model slower than Underwater Lab Tank model. This is may be due of some parameter for mathematical modeling is not complete because of the assumption of the project. These limitations of this project just focus on auto heading movement only. In conclusion of this project, the parameter of Underwater Glider was successfully obtained from SolidWorks. Next, the Underwater Glider was modelled by using mathematical techniques. Then, the Underwater Glider was modelled by using System Identification and it was verified with mathematical technique.

4.0 CONCLUSION

In conclusion, the Underwater Glider was successfully modeled by experimental technique by using System Identification in MATLAB Toolbox. The parameters that obtain from SolidWorks were used in order to model the Underwater Glider using mathematical techniques. This system identification model also had been verified by the mathematical model. This Underwater Glider was developed some of Slocum's characteristics. The Underwater Glider is an autonomous vehicle that is controlled by controlling the buoyancy and move horizontally by wings. This Glider is controlled by PIC and has a very low power consumption that makes glider moves on the water for a long time. This Underwater Glider was developed in order to monitor the underwater without compromising human's safety. In this project, the Underwater Lab Tank model has better performance which has faster rise time and settling time than swimming pool model and mathematical model. The rise time for an Underwater Lab Tank model is 0.0679s while the settling time for the model is 0.448s.

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