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PRELIMINARY EXPERIMENTAL STUDY ON DESIGNING BALLAST SYSTEM FOR AUTONOMOUS UNDERWATER VEHICLE

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ABSTRACT

Unmanned submarine commonly called Autonomous Underwater Vehicle (AUV) is one type of underwater robots used for underwater mapping. AUV is an underwater vehicle capable of automatically moving in water, controlled by humans on vessel. To build AUV is not easy as many components play important roles in the operation of AUV, one of which is active ballast. Calculations on the making and benchmarks of active ballast systems are still very rare. Active ballast is a set of equipment used to fill its tanks with seawater and to empty sea water from the tanks on submarines. These tanks are intended to balance submarines and for active ballast systems on submarines so as to be able to dive and float as needed. In this paper an experimental study was carried out on a tube resembling AUV with both fresh water and sea water to obtain ballast volume in AUV.

Keywords: *AUV,* ***active ballast, experimental study***

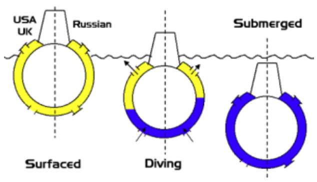
1. INTRODUCTION

Underwater vehicle technology has a very important role for archipelago nations such as Indonesia [1,2]. Since its water area is larger than its land, underwater technology is required to explore and keep or maintain its natural resources. So, underwater vehicle is needed [3,4]. Underwater rides widely developed by many researchers today are unmanned underwater robots. This robot is known as Autonomous Underwater Vehicle (AUV). AUV is one type of underwater robots that have attracted a lot of researchers in recent years [5,6,7].

In the 1970s, an initial investigation into the use of the AUV system was carried out, and in the 1980s the development of prototype technology and experiments began [8]. In the 2000s, AUV was already based on ICT. Currently there is a lot of research related to the navigation, guidance and control systems of AUV without ballast systems application to AUV although AUV design is to have a ballast system. AUV's ballast tank functions to store air and water. When the submarine is ready to dive, the large valves known as "kingstons", which are located at the bottom of the ballast tank, are opened to let it enter the sea. The air in the tank exits through the valves at the top, known as "wind holes". The submarine enters the water. When the submarine is ready to surface, the vents are closed and air pressure is pushed into the tanks. This blew water back through the kingstons, and the submarine went up. And this paper is about an experimental study carried out on a tube resembling AUV with both fresh water and sea water to obtain ballast volume in AUV.

2. AUTONOMOUS UNDERWATER VEHICLE

Basically, there are two ways to sink a submarine, namely by diving dynamically and statically. Many submarine models use static and dynamic methods when diving and such models are generally used by all military submarines. Figure 1 shows a flooding and blowing process in an active submarine ballast. In the process of flooding both water and air valves are open. This ballast system is to flow free air out of the tube through the air vents and through the water valve to fill or pump water into the ballast tank.



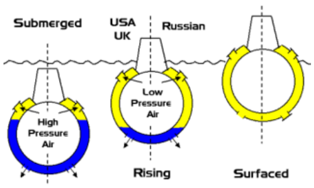


Figure 1. Flooding and Blowing of Ballast Systems

If viewed from the Law of Archimedes which states that an object that is partially or completely submerged into a liquid will experience an upward force which is the same as the weight of the liquid it displaces, an object completely or partially submerged in a fluid will get the weight to lift up that is equal to the weight of the fluid being transferred. The Specification of UNUSAITS AUV are listed in Table 1.

Table 1. specification of UNUSAITS AUV [9,10]

Weight	16 Kg
Overall Length	1500 mm
Beam	200 mm
Controller	Ardupilot Mega 2.0
Communication	Wireless Xbee 2.4 GHz
Propulsion	12V motor DC
Propeller	3 Blades OD : 50 mm
Speed	3.1 knots (1.5m/s)

3. BALLAST SYSTEM TESTING

The ballast system testing uses several tools and materials such as artificial ponds, fresh water, seawater, funnels, measuring cups, rulers, cutters, glue, stopwatches, 0.6 liter PVC pipes, 1 liter PVC pipes and 1.5 liter PVC pipes. The following is a picture of an artificial pool for the experiment as in Figure 2.

Figure 2. Experimental pool

The making of the ballast model begins with a 3-dim PVC pipe and plastic bottle cut according to the needs of 0.6 liters, 1 liter and 1.5 liters using a hacksaw. After having the appropriate size, 2 holes with a diameter of 1 cm are made for a hose of 1 cm to fix each. The purpose of making 2 holes is for the first hole to fill the water and for the second hole to get the air out of the PVC pipe and plastic bottle. Then the gluing of the pipes with the hoses is done using gun glue. Test material with PVC pipe and plastic bottle is shown in Figure 3.

Figure 3. PVC Pipe Active Ballast

From the experiment, the desired data are obtained, namely the depth of the bottle and PVC pipe filled with water (fresh water and sea water) and the time taken to fill the PVC pipe in stages.

- Freshwater Filling

Table 2. Data of PVC Pipe with Freshwater

Volume	0.6 liter		1 liter		1.5 liter	
	Depth (cm)	Time (s)	Depth (cm)	Time (s)	Depth (cm)	Time (s)
1/4 Part	3.5	15.8	3.8	8	1.3	14
2/4 Part	4.1	24	5.3	7	4.7	10.9
3/4 Part	6.3	34.5	6.9	7	6.5	13.1
1 Part	40	40	40	30	40	45

- Seawater Filling

Table 3. Data of PVC Pipe with Seawater

Volume	0.6 liter		1 liter		1.5 liter	
	Depth (cm)	Time (s)	Depth (cm)	Time (s)	Depth (cm)	Time (s)
1/4 Part	3.5	6.2	3.2	6.1	2.7	9.2
2/4 Part	5.2	6	4.7	6.4	6.3	15.3
3/4 Part	7	7.2	6.2	6	7.2	23.4
1 Part	40	9.3	40	9	40	38.8

4. DATA ANALYSIS OF EXPERIMENT RESULT

Based on the collected data then calculation of buoyant forces is made in accordance with Archimedes' law to find out the relationship between the experiments using Archimedes's law. The amount of buoyant force is formulated as follows:

Fa = ρcair Vb g

With the data interpolation, the graph can be obtained from each experiment using PVC pipes of different water conditions, namely fresh water and sea water. With this graph, it is easy to see the difference of each calculation data. The intended graphical results are as follows:

1. Graph of PVC pipe experimental data

- Freshwater

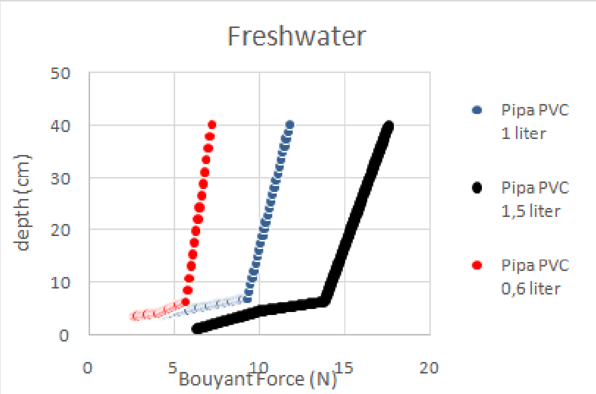


Figure 4. The graph of freshwater coming into PVC pipe

- Seawater

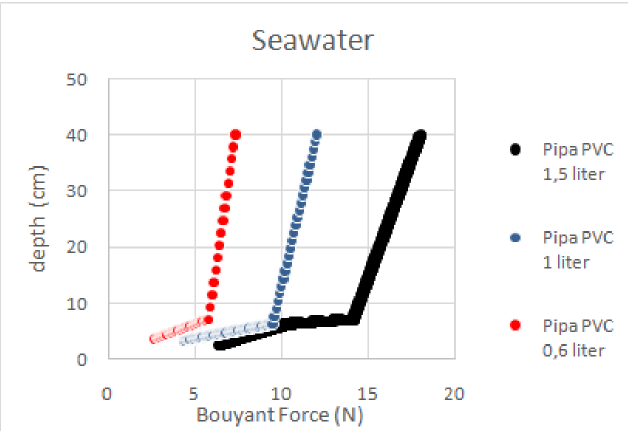


Figure 5. Graph of Seawater coming into PVC pipe

From the graph results it can be observed that there is an increase at some point. The increase occurs when the volume of the immersed object or the volume of filled water filled is ¾. To determine the formula of the empirical equation, division is made to each graph in accordance with the difference in the increase in the curve. The determination of the equation is done using the following linear equation formula:

From the calculation using the formula above, comes up the equation of each increase in curve for the graph as follows:

$$\frac{y-y_1}{y_2-y_1} = \frac{x-x_1}{x_2-x_1}$$

From the calculation using the formula above, comes up the equation of each increase in curve as of the graph as follows:

1. PVC pipe

- Freshwater

≤3 / 4 volume

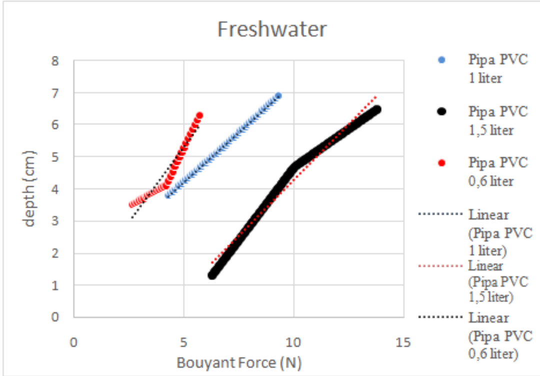


Figure 6. Graph of freshwater entering PVC pipe ≤ ¾ volume

From Graph of freshwater entering PVC pipe ¾ volume, the linear equation is as follows:

PVC pipe of 0.6 liter $y = 0.9333x + 0.6116$
PVC pipe of 1 liter $y = 0.62x + 1.1219$
PVC pipe of 1.5 liter $y = 0.6933x - 2.6616$

- ≥3/4volume

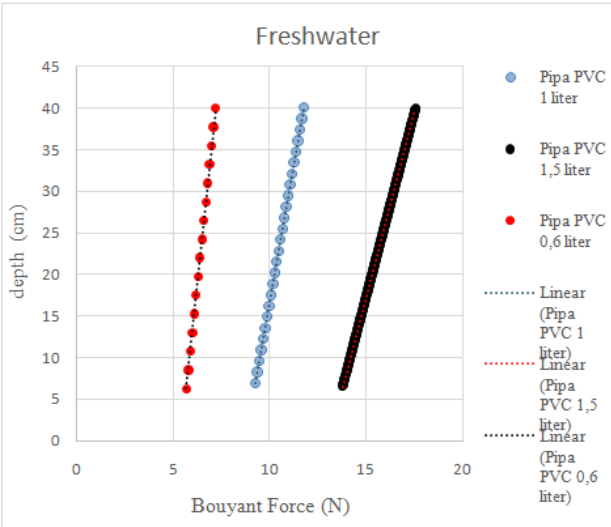


Figure 7. Graph of freshwater entering PVC pipe ≥ 3/4 volume.

From Graph of freshwater entering PVC pipe ≥3/4 volume, the linear equation is as follows:

- Freshwater

PVC pipe of 0.6 liter $y = 22.467x - 121.31$
PVC pipe of 1 liter $y = 13.24x - 115.97$
PVC pipe of 1.5 liter $y = 8.9333x - 116.69$

- Seawater

≤ ¾ volume

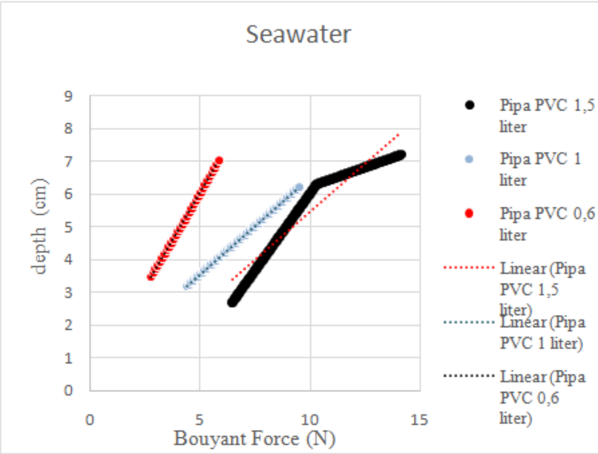


Figure 8. Graph of seawater entering PVC pipe ≤ 3/4volume

From Gafik sea water entering PVC pipe ≤ ¾ volume, the linear equation is as follows:

- PVC pipe of 0.6 liter $y = 1.1382x + 0.3491$
- PVC pipe of 1 liter $y = 0.5854x + 0.632$
- PVC pipe of 1.5 liter $y = 0.5854x - 0.3999$

≥ ¾ depth

From Graph of seawater entering PVC pipe 3/4 volume, the linear equation is as follows:

- Freshwater
  - PVC pipe of 0.6 liter $y = 22.467x - 121.31$
  - PVC pipe of 1 liter $y = 13.24x - 115.97$
  - PVC pipe of 1.5 liter $y = 8.9333x - 116.69$

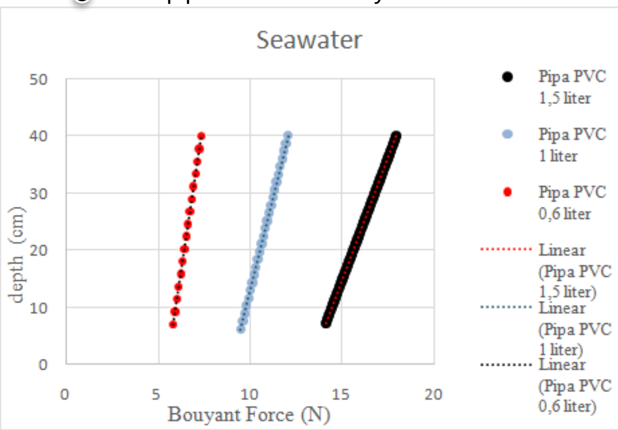


Figure 9. Graph of seawater entering PVC ≥3/4volume

From Graph of seawater entering PVC pipe ≥3/4 volume, the liner equation is as follow

- PVC pipe of 0.6 liter $y = 21.463x - 117.96$
- PVC pipe of 1 liter $y = 13.19x - 119.27$
- PVC pipe of 1.5 liter $y = 8.5333x - 113.42$

From the graphs of the results of experimental data, it results in curves that look relatively the same from each experiment. The changes in depth increase occur at the point ≥ 3/4 of the volume of water is filled into the PVC pipe. From the experiment, this can be used as depth parameter, that is, when the volume of water enters the ballast tank.

From the analysis of experimental data, the results can be used to establish the parameter for active ballast making. These parameters are listed in the table below as follows:

Table 4 List of Standard deviation of experimental data results

No	Type of tool	Medium	Parameter of active ballast		
			Time (second)	Volume (m^3)	Depth (cm)
1	PVC pipe of 0.6 liter	Freshwater	114.3	0.00019	17.724
		Seawater	28.7	0.00019	17.441
2	PVC pipe of 1 liter	Freshwater	52	0.000323	17.379
		Seawater	27.3	0.000323	17.692
3	PVC pipe of 1.5 liter	Freshwater	83	0.000484	18.045
		Seawater	86.7	0.000484	17.408

Table 4, it can be seen that in each experiment there is a standard deviation that functions as a means of finding out the values scattered at each point.

Based on the standard deviation data of the depth, by comparing those of the freshwater medium and those of the sea water one, it shows different results. The resulted standard deviation of the fresh water medium is higher than that of the seawater, indicating that the depth of fresh water has more various increases in value when there is a gradual filling process compared to that of the sea water. In its filling, the time the seawater takes to fill the active ballasts is relatively shorter than that the fresh water takes.

5. FORMULATION OF EMPIRICIAL EQUATION AND CALCULATE BALLAST VOLUME

Based the Archimedes law formula applying to the conditions of floating, swaying, and diving, it is known the ratio of density of matter to density of fluida.

Bouyancy force formula:

$$F_B = \rho_f V_b g \quad (1)$$

Matter density formula:

$$\rho_b = \frac{m}{V} \quad (2)$$

Notes :
m : Mass (kg)
v : Volume (m^3)
ρ_b : Density of matter (kg/m^3)

So that the formula equation is obtained in determining the active ballast as follows:

$$W > F_B \tag{3}$$

$$m_b g > \rho_f V_b\, g \tag{4}$$

$$m_b > \rho_f V_b \tag{5}$$

$$m_{kapal} + m_{ballast} > \rho_f (V_{kapal} + V_{ballast}) \tag{6}$$

$$m_{kapal} + \rho_{ballast} V_{ballast} > \rho_f (V_{kapal} + V_{ballast}) \tag{7}$$

$$m_{kapal} + \rho_{ballast} V_{ballast} > \rho_f V_{kapal} + \rho_f V_{ballast} \tag{8}$$

$$(_{ballast} - \rho_f)\, V_{ballast} > \rho_f V_{kapal} - m_{kapal}) \tag{9}$$

$$V_{ballast} > \frac{\rho_f V_{kapal} - m_{kapal}}{\rho_{ballast} - \rho_f} \tag{10}$$

From the equation (10) the volume of the ballast tank to be used by AUV is known as follows in Table 5.

Table 5. material of prototype

Matter type	Stell plate
Measurement unit (m)	1.000 x 0.2 x 0.003
Number of material	4
Mass (kg)	50.6
V_{AUV}	0.1884 m^3
ρ_{water}	1000 kg/m^3

V_{AUV}: 0.1884 m^3
M_{AUV} : 50.6 kg
ρ_{water} : 1000 kg/m^3

Solution:

$$V_{ballast} > \frac{\rho_f\, V_{AUV} - m_{AUV}}{\rho_{ballast} - \rho_f}$$

$$V_{ballast} > \frac{1000 kg/m^3 .1884\, m^3 - 50.6 kg}{7850\, kg/m^3 - 1000\, kg/m^3}$$

$$\frac{\pi}{4} D^2\, 1m > 0.246\ m^3$$

$$D > \sqrt{0.0254\, m^2}$$

$$D > 0.15\ m$$

$$D > 15\ cm$$

Based on the calculation results, to minimize systematic errors, a correction factor of 10% is used so as to gain the results of D > 16.5 cm. With the diameter obtained, the ballast volume is determined as:

$$V = \frac{\pi}{4} D^2 l$$

$$V = \frac{\pi}{4} (0.165\ m)^2\ 1\ m$$

$$V = 0.0213\ m^3$$

6. CONCLUSION

Based the results of the experimental analysis above, it can be concluded that:

1. The submarine is in a sinking state when the volume of water filled is 3/4 of the volume of the active ballast tank.
2. The fresh water produces a standard deviation that is greater than that of the seawater. It shows that the depth of the fresh water has a variety of increase values. If viewed from the time required, the filling of the sea water into the active ballast filling takes relatively shorter time than that the fresh water.
3. The active ballast design uses an active ballast system with ballast volume of 0.0213 m^3.

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REFERENCE

[1] Herlambang, T., Nurhadi H and Subchan., 2014. "Preliminary Numerical Study on Designing Navigation and Stability Control Systems for ITS AUV", *Applied Mechanics and Materials*, Trans Tech Publications, Switzerland. Vol. 49, pp. 420-425

[2] Herlambang, T., Djatmiko E.B and Nurhadi H., 2015, "Ensemble Kalman Filter with a Square Root Scheme (EnKF-SR) for Trajectory Estimation of AUV SEGOROGENI ITS", *International Review of Mechanical Engineering* IREME Journal, Vol. 9, No. 6. Pp. 553-560, ISSN 1970 – 8734. *Nov.*

[3] Ermayanti, E., Aprilini, E., Nurhadi H, and Herlambang T, 2015, "Estimate and Control Position Autonomous Underwater Vehicle Based on Determined Trajectory using Fuzzy Kalman Filter Method", *International Conference on Advance Mechatronics, Intelligent Manufactre, and Industrial Automation (ICAMIMIA)*-IEEE Surabaya Indonesia, 15 – 16 Oct 2015.

[4] Herlambang, T., Djatmiko E.B and Nurhadi H., 2015 "Navigation and Guidance Control System of AUV with Trajectory Estimation of Linear Modelling", *Proc. of International Conference on Advance Mechatronics, Intelligent Manufactre, and Industrial Automation,* IEEE , ICAMIMIA 2015, Surabaya, Indonesia, pp. 184-187, Oct 15 – 17.

[5] Oktafianto, K., Herlambang T, Mardlijah and Nurhadi H., 2015, "Design of Autonomous Underwater Vehcle Motion Control Using Sliding Mode Control Method", *Proc. of International Conference on Advance Mechatronics, Intelligent Manufactre, and Industrial Automation,* IEEE , ICAMIMIA 2015, Surabaya, Indonesia, pp. 184-187, Oct 15 – 17.

[6] Herlambang, T., Subchan and Nurhadi H., 2018 Position Estimation of ITSUNUSA AUV Based on Determined Trajectory using Kalman Filter (KF), ", International Conference on Research, Implementation and Education of Mathematics and Science (ICRIEMS), Yogjakarta, 7-8 May 2018

[7] Herlambang, T., Rahmalia, D and Yulianto, D., 2018, Particle Swarm Optimization (PSO) and Ant Colony Optimization (ACO) for Optimizing PID Parameters on Autonomous Underwater Vehicle (AUV) Control System, *Proc. of* The Second Internatonal Conference on Combinatorics, Graph Teory and Network Topology, University of Jember-Indonesia, 24-25 Nov 2018

[8] Yang, C. 2007. *Modular Modelling and Control for Autonomous Vehicle (AUV)*. Department of Mechanical Engineering National University of Singapore.

[9] Herlambang, T., Subchan and Nurhadi H., 2018 Design of Motion Control Using Proportional Integral Derivative for UNUSAITS AUV, ", *International Review of Mechanical Engineering* IREME Journal, Vol. 12, No. 11. Pp. 553-560, ISSN 1970 – 8734. *Nov*

[10] Herlambang, T., 2017, "Design Control System of Surge, Sway and Yaw Motion in Autonomous Underwater Vehicle using Sliding Mode Control (SMC) Method" Journal Of Mathematics and Its Applications (LIMITS), Vol. 14, No.1, page 53-60, ISSN 2579-8936. Mei.

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