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Design of Mechanics and Locomotion System For Box Culverts Inspection Robot

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Abstract

In Indonesia, flooding often occurs due to continuous heavy rain, based on observations, these conditions cause flooding. One of the problems currently faced by the Surabaya Public Works office is the existence of a wastewater drainage channel with concrete material that has a depth of 6 meters below the surface, which makes it difficult for workers to reach. Based on these problems, it is necessary to develop a technology that does not require human presence to directly monitor the conditions that occur in the drain pipe (gutter) using a mobile robot to monitor. The results of this study obtained output in the form of a mobile robot that can work in various fields, and to get a good response in control, the Ziegler-Nichols for Tuning system is used.

A. Introduction

Sewer pipes are buildings used as irrigation or disposal channels. According to the research conducted in the Office of Public Works Surabaya, there are various types of culverts there is box-shaped and circle-shaped round, from the dimension also there are various starting from 0,6 m x 0,6 m up to 7 m x 7 m, some have a length starting from 4 cm to 2 km, from the depth of the culverts are also different some have a depth of 0,4 m from the ground surface and some have a depth of up to 6 m from the ground surface. The culverts are certainly different from the culverts that are overseas such as in Japan, Malaysia, United States, Singapore, and Hongkong. The conditions of the culverts in Japan are very large and clean, other than in Indonesia filled with garbage and unused goods. Based on the observation of the condition of the cause of flooding in Indonesia, such as in big cities Jakarta, Surabaya, and Medan due to lack of attention to the environment, especially cleanliness in the culverts. The amount of garbage that accumulates in the culverts causes the flow of water to become seamless due to the garbage clogging the drain pipes and the overflowing water.

Figure 1. Conditions of the culverts in Indonesia.

The problem that comes in the presence of the culverts that can not be reached by the workers to enter the sewers so that it can not be monitored by the Public Works Office of Surabaya, so it is necessary to develop a technology that does not require human presence to directly monitor the circumstances that occur in the culverts. By using a mobile robot to perform monitoring. The use of mobile robots is one of the innovations in the form of robots monitoring the culverts abroad, but because the condition of the culverts in Indonesia is different from those in other countries. The most distinct of the culverts that exist in other countries is in Indonesia the culverts are used to carry the flow of water, the flow in the culverts is open [1]. As a result, a robot capable of inspecting specific culverts is required. It is possible to think of robots as an automatic instrument that can perform human-like tasks [2]. In general, robots are classified into many segments, including manipulator robots, mobile robots, land robots, which are further subdivided into legged and wheeled robots, water robots (submarine robots), and flying robots (air robots), all of which are designed and manufactured to meet the needs of their users [3]. As modern technology advances, robots are increasingly being utilized to help with human tasks that are known to be challenging and risky for people to complete, which can lower the number of workplace accidents [4]. The robot's body and wheels are made to function in both situations. The robot's work system may encounter difficulties such as pebbles,

gravel, trash, and uneven soil during dry conditions. Additionally, when the culvert is wet, a sizable water discharge must be passed. In order to monitor the culvert, a camera system will be employed to wirelessly drive this mobile robot, which will be designed to traverse a variety of fields and circumstances. Furthermore, robots must be able to communicate with operators outside by sending an interface to the microcontroller. The basic objective of human-robot interaction is to develop principles and algorithms for robot systems that can directly, safely, and effectively interact with humans. In Indonesian, human-robot interaction is defined as human-robot interaction expressed at three levels: humans as full robot controllers, humans as robot operator managers, and humans and robots are in equality. The definition of interaction necessitates communication between humans and robots. Human-robot communication can take many different forms, but it is primarily determined by the proximity of humans and robots [5], [6], [7]. In order to create, develop, and implement forms of human-robot interaction that are in line with needs, a number of paradigms, theories, and taxonomies of human-robot interaction have been defined and developed in earlier studies [8], [9], [10].
This paper aims to implement robotic mechanics and PID controllers applied to robots and analysis of controls when used to control motor speeds. The design procedure was taken in several previous studies before innovating on mechanical design and robotic control design. This paper is compiled as follows: Part B research methodology. Part C describes result and discussion. Part D presents result and discussion. Part E contains acknowledge.

B. Research Method

The first stage carried out by the researcher is a literature study by reading several journals about previous research on amphibious robots, several journals used as sources by the researcher are journals with research that focuses on mechanics and control systems addition to conducting literature study research also collects data on drainage channels at the Surabaya City Public Works Department. After the literature study is complete, the next step is to create a mechanical design plan that will be used for research and design a low-level control system that will be applied to the final assignment, then after completing the design process, the researcher carries out the manufacturing process on the mechanical part of the robot starting from making the wheels then making the robot, after the robot goes through the manufacturing process is complete, the next step is to test the robot and analyze the mechanical system and low-level control system.

1. Theoritical Background of Mechanics

1.1 CFD Analisys

Numerical testing was done at an early stage once the robot design was completed. These numerical tests use tools such as simulated software on a computer. In this simulation, several tests include hydrodynamic or CFD testing, pressure testing on inspection, and testing of robotic movements. The data taken later will be the analysis data for the next process. Hydrodynamic testing is here to determine the characteristics of fluid against the robot. In this simulation is done software using Solidwork Flow simulation. The Data obtained from this simulation is a barrier style, where it is the liquid component of the coefficient of the barrier. The barrier style coefficient can be written with the following equation (1):

$$CD = 2Fd/(\rho \times v2 \times A) \quad (1)$$

Where:
CD = drag coefficient
ρ = air density (kg/m3)
V = airflow velocity (m/s)
A = Body Area (m2)

1.2 USV Hull Calculation

For USV not to sink at the time of being burdened, the force to press down from USV must be smaller than the water lift, so that the hull that is made must have sufficient volume to make the water lift larger. To calculate the payload (displacement capacity) equation is used (2) as follows.

$$\nabla = \rho \times V \quad (2)$$

From the equation (2), then to find the minimum volume of the stomach to float is:

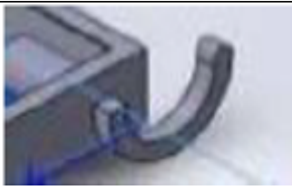
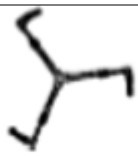
$$V = \nabla/\rho \quad (3)$$

1.3. Comparison of wheels mechanism ever used in previous research

Comparisons of wheel drive system mechanisms that have been researched by some previous researchers such as the mechanisms of All-Terrain Wheels, Spoked Wheels, Elliptic-Curve Legs, e-Rowing, and e-Rowing-EGM comparisons of the advantages of each mechanism will be shown in **Table 1**. This table is used as a reference for selecting a mechanism to be used in the design of the final prototype wheel mechanism project. Because in Indonesia has the culverts with extreme terrain, so it takes a wheel that is relevant to the existing terrain.

Table 1. Wheeled Mechanism comparison table.

The Mechanism Name Used	**Wheel Design**	**Advantages of each Mechanism**
All Terrain Wheels		Requires a small torque while passing uneven terrain. [11].
Spoked Wheels		Can run high speed and can pass through in uneven terrain [12].

Elliptic-Curve Legs		This model is more suitable for moving in muddy terrain [13].
Whegs		Help across irregular terrain and climb obstacles [14].
eRowing-EGM		Can run on uneven terrain, and can work in all terrain i.e. watery and not watery [15]

2. Theoritical Background of Control

2.1. PID Control for Low Level Control

After a literature study conducted with research conducted by Goushing [16] which developed the PID control for a PC-based DC motor speed arrangement, and Prof. Ashis Patra and Manoj Kushwah [17] also used the PID control for motor speed control with this speed control system at the current final project using the PID control with the support sensor of the Rotary encoder sensor. The rotary Sensor serves as a motor speed setting when the robot performs the process of running or maneuvering while avoiding obstacles, it also uses the PID control to keep the speed of each motor stable and faster in response to the control diagram block as found in **Figure 2**.

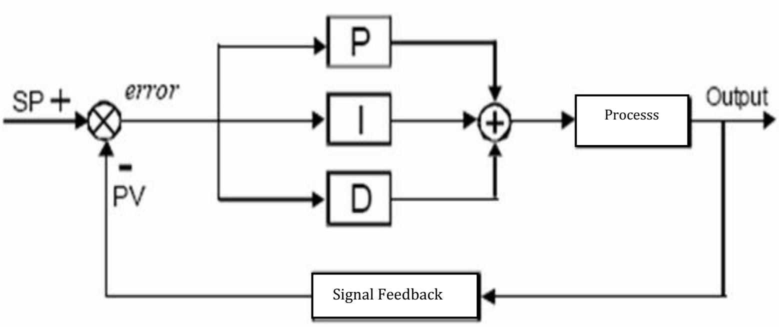


Figure 2. Planning control Robot System with PID.

2.2. Ziegler-Nichols Method

2.2.1. Ziegler-Nichols Method 1

The 1st method is based on the plant's response to ladder inputs in open-ended Kalang. Plants that do not have an integrator, resulting in a response curve to the ladder input such as the S curve in **Figure 3**. The plant response curve is used to locate L delay time and T. Time constants.

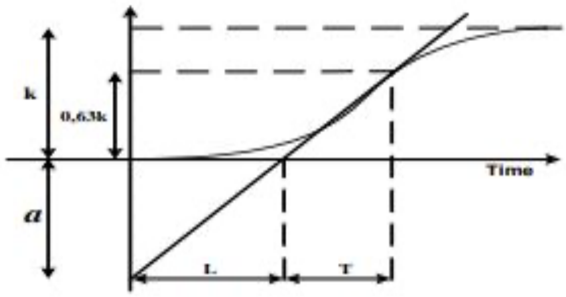


Figure 3. S-shaped response curve.

2.2.2. Ziegler-Nichols Method 2

In the 2nd method, the reasoning is done in a closed plant where the reference input used is the function of the ladder (step). The controllers on this method are only proportional controllers. KP, increased from 0 to the critical value of Kp, thus obtained an output that continuously oscillate with the same amplitude. Kp's Critical value referred to as ultimate gain. The resulting output response in 3 proportional gain conditions is shown in **Figure 4**. The system can oscillate stably at the time of Kp = Ku.

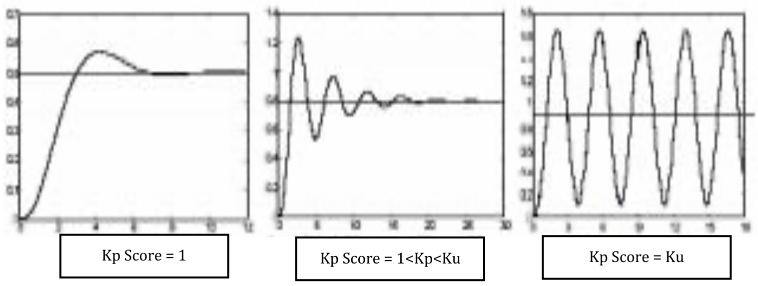


Figure 4. Characteristics of output a system with the addition of Kp.

C. Result and Discussion

1. Mechanical Result

1.1. USV Hull Calculation

Total load capacity (∇) = 4 kg, water type Masssa (ρ) = 1000 kg/, the minimum volume of the hull is:

$$V = \nabla/\rho \tag{4}$$

$$V = 4/1000$$

$$V = 0.004 \text{ m3}$$

The design of the hull is composed twice half the cylinder with the details of the radius of 1.5 cm and height 26 cm and a rectangle with the details of the length of 27 cm, width 26 cm, and body height 6 cm. So that the volume of the hull (Vhull) is:

$$Vhull = \pi \times r^2 \times T + P \times L \times H \tag{5}$$

$$Vhull = 3.14 \times 0.0152 \times 0.26 + 0.27 \times 0.26 \times 0.06$$

$$Vhull = 0.00439569 \text{ m3}$$

Therefore, displacement capacity USV is:

$(\nabla) = 1000 \times 0.00439569\ m3 = 4.39569\ kg$

After the body is done and the next step connection is to perform a waterproofness test on the body of the robot and test to find out how much displacement capacity in the hull of the attraction when the rides are moving or during silent rides. The USV test is done at Lake. The hulls design and the payload mass carried by USV have a significant effect on USV robot buoyancy. If an overload of the robot occurs itself (the payload) may result in the robot sinking. Based on mechanical design, the USV robot has a displacement capacity of 4.39569 kg. Whereas the payload mass brought by the robot by 3 kg, then USV can float on the surface of the water. In terms of its waterproofness also the body of the robot has not leaked when in the dip.

1.2. CFD Analisys for Body Robot

In the test result hydrodynamics is sought-after data drag force (FD) as the robot moves forward in water. Done with the speed of the robot 2 m/s. Visualization of advanced motion simulation under **Figure 5**.

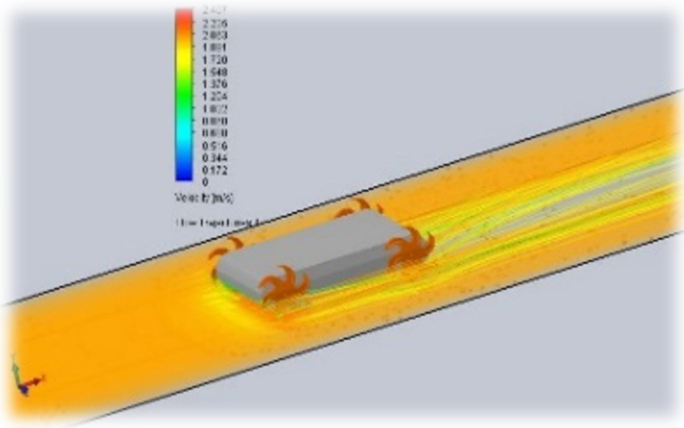


Figure 5. Streamline visualization on motion forward with a speed of 2m/s on Body Robot.

Streamline shows different shapes as well as different colors. In the form of a steady flow of ramps and straight when hitting the robot body will form the arch until the vertex occurs when the speed is high enough. A streamlined difference is not too striking because the speed difference is also not very significant. From the form of the flow can be seen also the surface of the body that is getting pressure, according to **Figure 6** below.

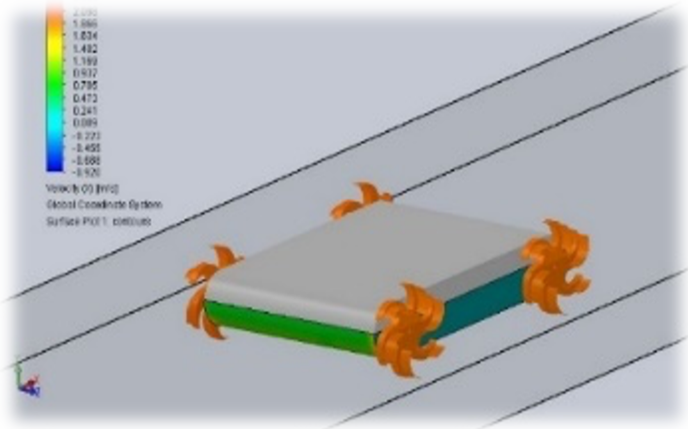


Figure 6. Visualization of Body Pressure Contour When Moving forward with Speed 2 m/s.

It can be seen as in Figure 9 surface body has different color. The green color at the front of the robot body indicates that the surface is experiencing the highest when moving forward compared to the blue in the side of the ride that is not subjected to pressure due to water flow. The highest pressure gained by the highest rides is the green color. Although it goes forward all parts of the body of the ride still experiencing pressure but not as wide as the front body of the rides in the simulation is mentioned the minimum limit of pressure available on the robot body of -0,920 m/s and the maximum limit of the pressure in the body of the robot at 2,330 m/s. From the simulation you get a graph of the speed response to the blocking style shown in **Figure 7**.

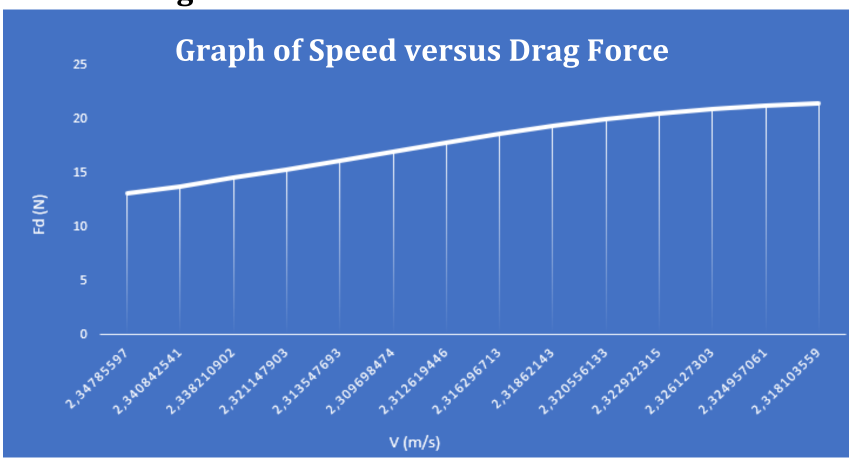


Figure 7. Graph of advanced motion response on Body Robot.

In **Figure 7** is shown a graph of the speed response to the drag force (Fd). With variation of speed according to the number of iterations that have been done by the software Solidworks. Given a random speed but when compared to one by one data obtained from simulated speed compared with the force in the result of a straight to the outcome because if the speed increases then the drag force will also increase, and vice versa if the speed is reduced the barrier will also decrease. But the results of the graph can not be said to be linear, the lack of the influence of the style of the resistance to speed due to the form of fluid flow that results in the movement of a different object at different speeds. But there are times when a certain speed range of the force has a linear value. Because at that speed range is in the characteristic area of turbulence. On a certain form of field it is easy to obtain or reside in the turbulence characteristic area. But for objects that have complex shapes it is quite difficult to reach those values.

2. Controller Result

Results found for the critical gain with a value of 0.5 and for the Corresponding period with a value of 1.5 will be obtained the result as in the following **Table 2.**

Table 2. PID table results from tuning Method 2.

Controller	Kp	Ti	Td	Kp	Ki	Kd
P	0.3	Inf	0	0.25	0	0
PI	0.25	1.25	0	0.225	0.18	0
PID	0.3	0.75	0.1875	0.3	0.4	0.05625

Once known the values of Kp, Ki, and Kd are then inserted into the block control system that is in Simulink the result of the actual speed Chart of reference appeal will be shown in Figure 8.

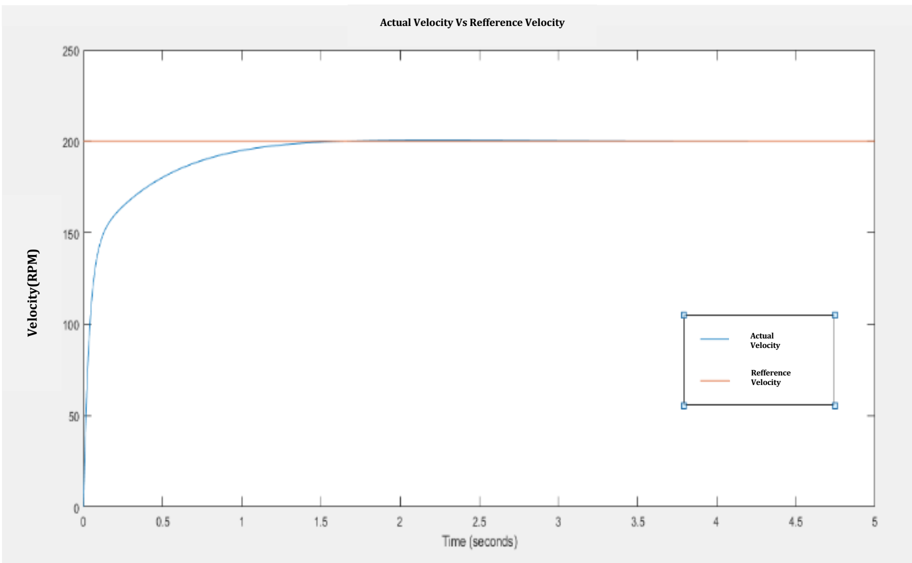


Figure 8. Graphic Response Actual Velocity Vs Reference speed in RPM.

Experiments conducted using Myrio the first time using a setpoint of 200 rpm without using PWM input from the remote control to know how good the response control PID by using tunning PID Ziegler-Nichols. Then the PID parameter that has been obtained through MATLAB is then applied to the program given input step **Figure 9** indicates actual motor condition.

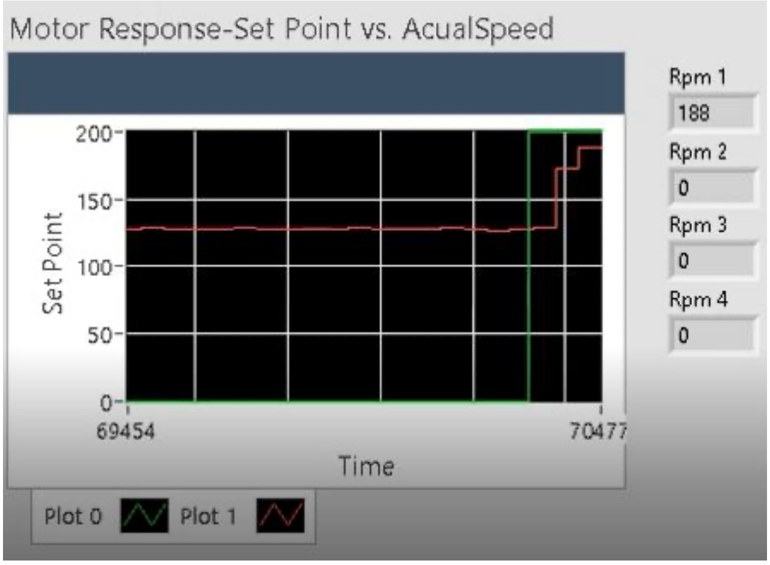


Figure 9: Graphic Response Actual Velocity in Motor DC Tested With Myrio.

From **Figure 9** The following demonstrates that the actual speed response of the motor that has been achieved with the parameters of PID that has been determined according to the calculations performed in MATLAB and which has been simulated is good but there is little noise, it is caused by the error of reading on the Rotary encoder. The read signal response to Myrio has an error of 3%. In response to the rotation of the motor that looks already have a good response and not dashed. Then **Figure 10** is the actual image of the motor speed response results when given a PWM input from the remote control and walking on land without Obstacle. The following is the actual speed when given an 80% duty cycle with the PID parameter set at MATLAB before. The legible signal response has a 3% error for the visible speed of the motor response as well as having a good response and not dashed.

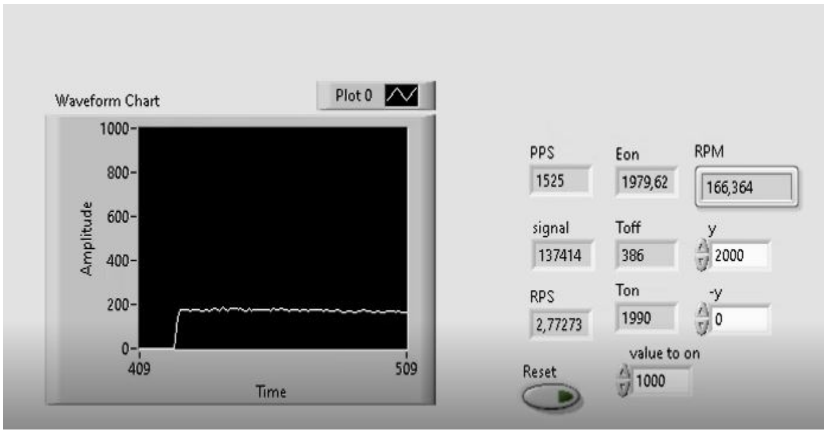


Figure 10. Motor response result when given PWM Input from RC when walking on land without Obstacle.

Then **Figure 10** is the result of the actual motor speed response image when given a PWM input from the remote control and walking on the water. The following is the actual speed when given a 100% duty cycle with the PID parameter set at MATLAB before. The legible signal response has a 3% error for the visible speed of the motor response as well as having a good response and not dashed.

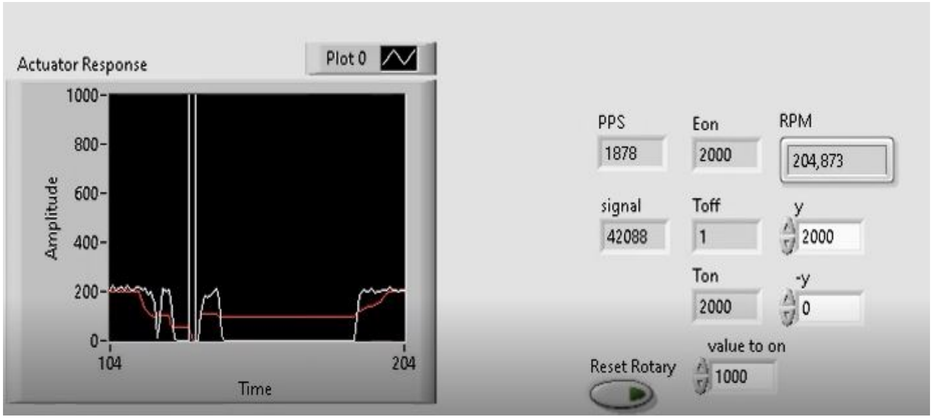


Figure 11. Motor response result when given PWM Input from RC when walking on the water.

D. Conclusion

In the simulated CFD tests, certain key parameters were examined, including pressure, velocity, airflow, vortex, and drag coefficient (Cd). The purpose of this analysis was to achieve the aerodynamics of the robot's airfoil body while walking on the water surface. The simulation results showed that the drag coefficient over the body of the robot was very small during movement on water, indicating an efficient hydrodynamic shape with minimal resistance. Further analysis involved calculating the buoyancy characteristics of the robot. With the estimated gastric volume of approximately 0.00439569 cubic meters and payload weight—including the electronic box—of 3 kilograms, water testing between 1 and 2 meters depth was conducted. The test also revealed a waterline value of the Unmanned Surface Vehicle (USV) at about 0.03 meters, half the diameter of the hull, showing that the robot is buoyant enough and stable under normal load conditions. In motion control, the Ziegler-Nichols tuning method was employed to obtain optimal PID (Proportional-Integral-Derivative) controller parameters. This process essentially gave the best possible values of the controller coefficients, resulting in an improved motor response with quicker and more accurate operation. The first attempt at using proportional (P) or proportional-integral (PI) control alone was insufficient since it could not reach the desired set point. But under the complete PID control with the coefficients P = 0.3, I = 0.4, and D = 0.05625, the system experienced stable and accurate speed control, satisfying the requirements for accurate robot movement.

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