International Journal of Electrical Engineering, Mathematics and Computer Science

E-ISSN: 3048-1945
P-ISSN: 3048-1910

Research Article

PID Tuning on Sediment Detection Boat Using Simulink

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Abstract: The PG45 DC motor is a drive system used on sediment detection boat. To achieve the desired stability and speed, it is necessary to apply a control system to the sediment detection boat drive system. Control systems need to be tuned to ensure that they function properly and are responsive to changes. In order to complement the previous research, further research was carried out focusing on determining the PID control parameters on the angular speed of the PG45 DC Motor using Simulink. The PG45 DC motor works based on the Arduino programming algorithm that has been designed so that it can rotate at a predetermined speed. This research modeled the sediment detection ship system on Simulink with a similarity rate of 94.09%. The results of this study indicate that the tuning method used, namely trial and error, produces good control on the sediment detection ship system model that has been assembled in Simulink with the value of Kp = 100; Ki = 5; Kd = 15 obtained the value of rise time = 0.2474 seconds and settling time = 0.4104 seconds and overshoot = 0.2175%%.

Keywords: DC Motor; PID; Arduino; DC Motor Modeling; Simulink

Received: 01 March[th] 2025
Revised: 15 March[th] 2025
Accepted: 29 March[th] 2025
Published: 05 June[th] 2025
Curr. Ver.: 05 June[th] 2025

1. Introduction

Increased human activity along the river has affected the river ecosystem. Activities that impact the river include logging upstream. This activity causes increased soil erosion along the river. As a result, the amount of sediment in the river increases and causes siltation of the river (Asdak, 2023).

In Indonesia, polluted waters are often found around residential areas, where household waste is channeled into rivers, making the water appear dirty and murky. Watersoluble dirt eventually settles on the bottom of the water, causing sedimentation. Therefore, there is a need for a device that can detect sedimentation in waters by measuring the height of sediment deposits underwater. Knowing the presence of sediment deposits at the bottom of the water makes it possible to take preventive measures so as not to cause siltation of rivers, degradation of water quality, and disruption of aquatic life.

One of the efforts in supporting the achievement of clean waters and preventing river siltation, degradation of water quality, and disruption of aquatic life is the mitigation of sediment removal. The sediment detection vessel is a device equipped with a PG45 DC motor as the main drive and an adjustable ultrasonic sensor as a sediment detector. This tool uses a PID algorithm that serves to control the movement of the PG45 DC motor.

Previously there has been research to measure sediment. Entitled "Monitoring River Sediment by Optimizing Arduino Capabilities Controlled by the PID Algorithm" conducted by Muhammad Khoirun Faza, Sri Arttini Dwi Prasetyowati, and Bustanul Arifin in 2023. This research designs a tool in the form of a sediment volume measuring ship. This tool uses a PID algorithm that functions to control the movement of the PG45 and PG28 motors. The measured values are length, width, height and volume. Adjustable infrared sensor switch and rotary encoder are used as a reference for measuring sediment volume by processing data in the form of Arduino Mega 2560. The results of this study are able to read the volume of sediment. The comparison value between the original value and the value of the measurement results of the tool is implemented in the form of a percentage error value. In 10 trials, the average error value for length was 2.13%, width was 7.09%, height was 0.95%, and volume was 4.74% (Prasetyowati et al., 2022).

Complementing previous research that performed PID tuning by interacting directly with the device, in this research PID tuning is performed using the Simulink tool feature of the Matlab software. PID control needs to be tuned for DC motors so that the system can achieve the desired performance. PID tuning using software has several advantages, namely saving component life, speeding up the tuning process, exploring a freer combination of PID parameters, and consistency of results with the same input.

2. Research Method

In the domain of control systems, a controller can be defined as a dynamic subsystem that has been incorporated with the objective of altering the mathematical equations of a given plant. The primary function of a controller is to minimize error, defined as the deviation between the setpoint value and the actual plant output. In this scenario, the setpoint functions as the target reference value, while the plant output signifies the actual measured value. The effectiveness of a control system is determined by its capability to minimize error values. Consequently, the PID (proportional-integral-derivative) controller must be tuned to ensure that the control system functions properly and responds to changes(Ogata, 2020).

The research methodology employed in this study consists of several stages designed to achieve the research objectives. This methodology involves literature studies, data collection, system identification, model simulation, result analysis and conclusion.

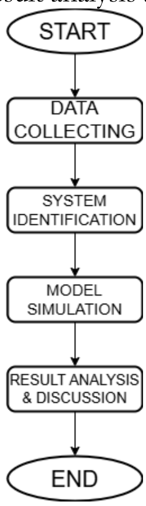

Figure 1. Research Flowchart

2.1. Literatur Studies

This literature study aims to collect theories that form the basis of the research. The study includes an understanding of theories, concepts, and methods relevant to building a logical and structured framework. Literature sources can be books, scientific works, journals, and articles on the internet that support the writing of this journal.

The following block diagram illustrates the propulsion system of a sediment detection boat.

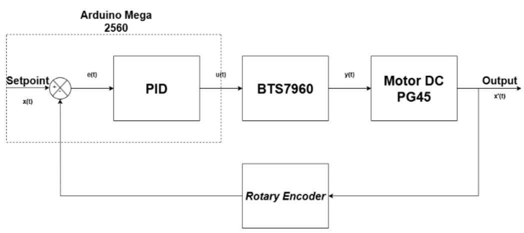

Figure 2. block diagram propulsion system of sediment detection boat.

Description:

- Reference input x(t), in the form of the target motor speed in RPM.
- System error e(t), which indicates the deviation between the setpoint value and the actual value.
- Control voltage u(t) with a range of 0-5 Volts.
- Output voltage y(t) in the range of 0-24 Volts.
- Actual motor speed x'(t) measured in RPM.

2.2 Data Collecting

The collected data encompasses the input voltage and rotational speed of the motor. The input voltage is measured directly at the terminals of the PG45 DC motor using an appropriate measuring device, such as a multimeter, to ensure the accuracy of the voltage value supplied to the motor during the data collection process.

Concurrently, the motor rotational speed measurement is conducted on the motor shaft through two methods for the purpose of data validation: a digital tachometer and software-based monitoring employing a rotary encoder on the PG45 DC motor connected to an Arduino. The speed data recorded from both methods is then compared to ensure the consistency and reliability of the measurement results. The utilization of these two measurement methods has been demonstrated to facilitate the acquisition of more accurate and valid data concerning the rotational speed performance of the tested motor. Eq. (1) is used to calculate error relative of PG45 DC motor.

$$Error\ relative(\%) = \left|\frac{tachometer\ data - serial\ monitor\ data}{tachometer\ data}\right| \times 100 \tag{1}$$

After testing the PG45 motor, the input voltage and output rotational speed data of the motor were obtained as shown in Table 1.

Table 1. results of testing the pg45 DC motor.

PWM	Voltage (V)	Tachometer data (RPM)	Serial monitor data (RPM)	Error relative (%)
0	0	0	0	0
10	0.8	15.7	15.63	0.446
20	1.6	33.0	33.13	0.394
30	2.5	51.8	51.88	0.154
40	3.3	70.4	70.31	0.128
50	4.2	89.1	89.01	0.101
60	5.0	108.0	108.44	0.407
70	5.8	127.1	127.88	0.613
80	6.7	146.1	147.19	0.748
90	7.5	166.3	166.88	0.349
100	8.3	186.2	186.88	0.364
110	9.2	206.6	207.19	0.285
120	10.0	225.7	226.25	0.244
130	11.7	246.3	246.88	0.236
140	12.5	267.6	267.81	0.078
150	13.4	288.7	288.75	0.017
160	14.2	303.1	301.88	0.403
170	15.0	324.6	327.38	0.857
180	15.8	345.9	345.63	0.078
190	16.7	367.0	367.50	0.136
200	17.5	388.4	386.88	0.392
210	18.3	406.6	404.76	0.452
220	19.2	427.6	426.0	0.374
230	20.0	447.7	447.88	0.040
240	20.8	456.2	467.19	2.409
250	21.7	475.9	476.56	0.138
255	22.4	497	495	0.402
	average error value			0.38

In table 1 there are columns of PWM, input voltage (V), tachometer (RPM), serial monitor (RPM), and relative error (%). The relative error value is obtained using equation (2). This testing process aims to identify the relation between changes in input voltage and the dynamics of DC motor rotational speed.

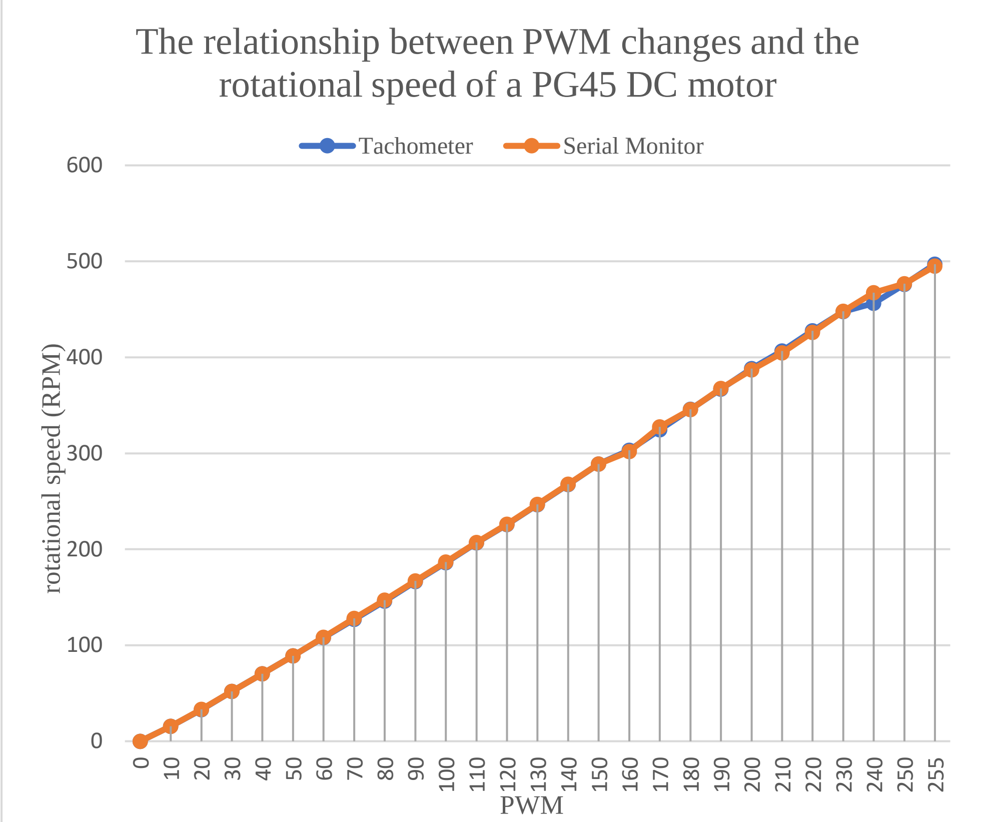

Figure 3. Graph showing the relationship between PWM changes and the rotational speed of the PG45 DC motor.

Fig. 3 shows that there is a linear relationship between the PWM value and the motor rotational speed (RPM). As the PWM increases, the RPM also increases, the change of PWM to the motor rotational speed shows that PWM control is effective in regulating the motor speed. A comparison between the rotational speed measured by the tachometer and that measured via the serial monitor shows that both measurement methods give very similar results. The average relative error of 0.38% shows that the Arduino-based measurement system is quite accurate. The relative error varies from 0.017% to 2.409%. The higher error values at some points for example at PWM 240 may be due to external factors or instability in the measurement. Most of the relative errors are below 1%, indicating good consistency in the measurements.

2.3 System Identification

There are two main categories of mathematical modeling: theoretical modeling and experiment-based modeling. In theoretical modeling, a dynamic model is derived by applying laws of physics, mathematics, and other things. Meanwhile, experiment-based modeling is based on the measurement of input and output data through system identification. The System Identification Tool in Matlab is a tool for creating mathematical models, and is based on collecting input and output data from the system(Fahmizal & Susanto, 2018).

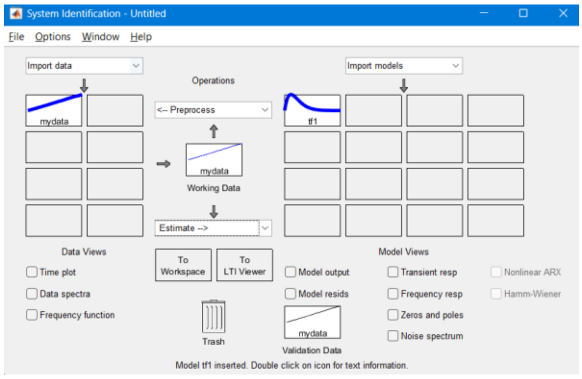

Figure 4. System Identification Interface in Matlab

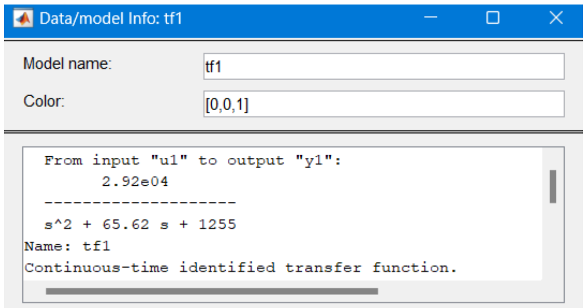

Figure 5. Mathematical model of PG45 DC motor

$$\frac{2.92e04}{s^2+65.62s+1255} \tag{2}$$

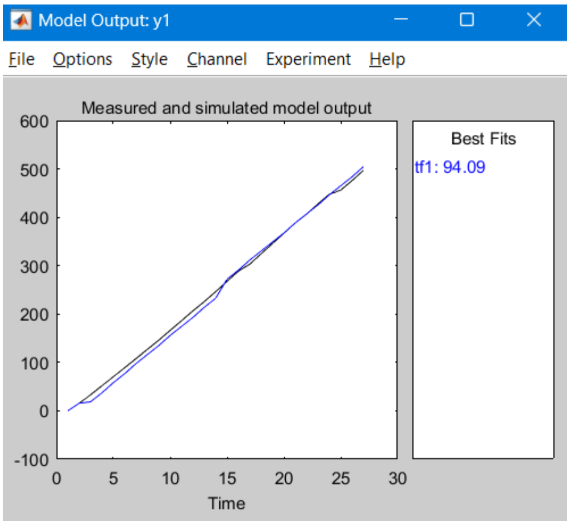

Figure 6. Output model graph

The model that has been made has a similarity of 94.09% with the real system.

2.4 Model Simulation

Simulink is used to simulate the sediment detection vessel system and then tune the PID control. The PID needs to be tuned to ensure that the control system functions properly and is responsive to changes.

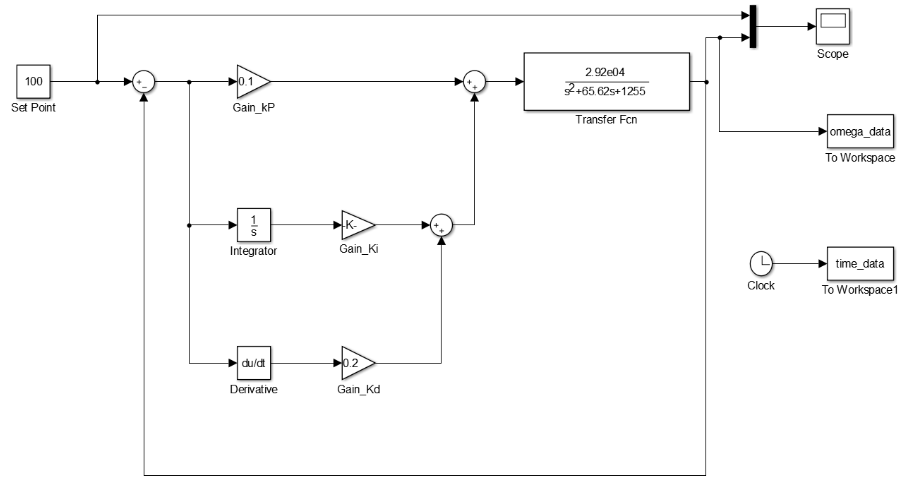

Figure 7. Simulink interface of the system

The values in the Kp, Ki, and Kd blocks can be changed to produce an output that matches or is closest to the setpoint.

After testing the tuning using system simulation in simulink with a setpoint of 100, the test results are obtained as in table 2.

Table 2. Tuning test results on Simulink

No.	Kp	Ki	Kd	*Rise time* (s)	*Settling time* (s)	*Overshoot* (%)
1	1	0	0	1.1107	NaN	27.7919
2	1	0	1	NaN	NaN	NaN
3	10	0	1	0.3605	NaN	50.6155
4	10	1	1	0.3551	9.6262	54.6773
5	10	5	1	0.3357	NaN	70.0437
6	10	5	5	0.6288	5.0123	13.7091
7	10	5	10	1.1647	6.9236	18.7689
8	20	5	10	0.7829	7.2569	6.7491
9	50	5	10	0.3133	0.4872	1.3698
10	70	5	10	0.2192	0.6179	4.4933
11	70	5	15	0.3776	0.6531	0.7181
12	100	5	15	0.2474	0.4104	0.2175

3. Result Analysis and Conclusion

With the combination of inputs in experiment 1, the time required to reach the setpoint (rise time) is 1.1107 seconds, exceeds the setpoint (overshoot) by 27.7919%, and cannot reach a stable condition (settling time).

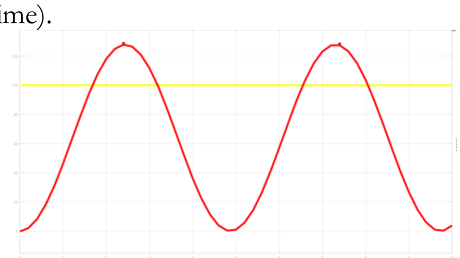

Figure 8. System response graph of experiment 1

With the combination of inputs in experiment 4, the rise time value is 0.3551 seconds, the settling time is 9.6262 seconds, and but the overshoot value is too large at 50.6155%. Seen in Figure 12, the graph starts to approach the setpoint line (convergent).

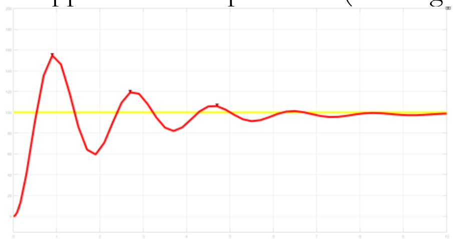

Figure 9. System response graph of experiment 4

With the combination of inputs in experiment 9, the rise time value is 0.3133 seconds, the settling time value is 0.4872 seconds, and the overshoot value decreases to 1.3698%. Experiment 9 was conducted by increasing the Kp value, this is in line with the theory when increasing the Kp value will reduce the rise time.

Figure 10. System response graph of experiment 9

With the combination of inputs in experiment 12, the rise time value is 0.2474 seconds, the settling time value is 0.4104 seconds, and the overshoot value is 0.2175%. In experiment 12, the results obtained were closest to the setpoint.

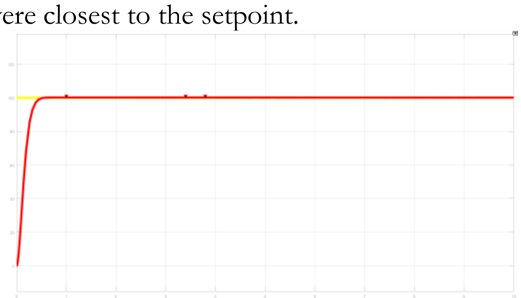

Figure 11. System response graph of experiment 12

Based on the results of the research and analysis carried out on the PG45 DC motor and the simulation of the sediment detection ship system in Simulink, the conclusion is obtained:

1. The PG45 DC motor on the FTI Unissula sediment detection ship has good performance. The comparison between input and output of this DC motor is directly proportional.
2. The tuning of the PID controller parameters carried out through simulation on Simulink software produces a satisfactory system response graph, with a rise time value of 0.2474 seconds, a settling time of 0.4104 seconds, and a very small overshoot, which is only 0.2175%. These results show that the system has a fast, stable response, and minimal oscillation beyond the setpoint.
3. From the analysis of the effect of PID control parameters, it is known that changes in the Kp (proportional gain) value have a significant effect on the rise time of the system. Meanwhile, adjusting the value of Kd (derivative gain) has an impact on reducing the overshoot value and also improves the settling time or the time it takes for the system to reach a stable state. Thus, the selection and adjustment of Kp and Kd parameters are very important to obtain optimal system performance

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