UDC 629
DOI: 10.15587/1729-4061.2023.274713

IDENTIFIYING THE PID-N METHOD PERFORMANCE FOR SPEED CONTROL OF BLDC MOTOR PROPELLER ON CATAMARAN SHIPS MODEL

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Some archipelagic countries must have wide sea. This condition means that there is transportation of goods and people problem. Therefore, an effort has been made to explore renewable energy especially solar energy. In this research, a BLDC (Brush Less Direct Current) motor propeller is applied, and PID-N (Proportional, Integral, and Derivative – Filter Coefficient) method for Catamaran ship speed control. Where PID-N has additional filters such as P, I, and D; however, the advanced performance of this control uses RLS (Recursive Least Square) actuator modeling is the most systematical and flexible design. The experiment includes the speed response of ships with payload and without payload, as well as changes in speed settings. The results show that the ship's speed control using the PID-N has smooth and definite speed control. The PID-N design is systematical, easy and quick for the control designer to change the actuator or sensor performance, if there will be any actuator or sensor replacement with different specifications, which is required in commercial. As it is known, in commercial design, time and method are crucial and has to be effective. The PID-N control method shows its superiority. In detail, the Catamaran speed setting is incremented from 0.4 m/s to 0.6 m/s without payload, the average settling time is 6 seconds with the average error speed 0.071 m/s in the set speed 0.6 m/s. For setting speed increased by 0.4 m/s to 0.6 m/s with payload, settling time gets longer, 7 to 13 seconds with the average error speed 0.01 m/s in the set speed 0.06 m/s. It performs small errors and fasts settling time. The ship model has experimented on an artificial pond, it is related to the proportional small sea wave. The research also shown the ratio of electric power consume toward speed setting is in exponential formula

Keywords: Catamaran ship, ship speed control, PID-N Control, BLDC motor, propeller

Received date 29.03.2023
Accepted date 02.06.2023
Published date 30.06.2023

***How to Cite** Setiawan, B., Firdaus, M. K., Wibowo, S., Agafta, I., Zain, F. (2023). Identifiying the PID-N method performance for speed control of BLDC motor propeller on catamaran ships model. Eastern-European Journal of Enterprise Technologies, 3 (2 (123)), 35–43. doi: https://doi.org/10.15587/1729-4061.2023.274713:*

1. Introduction

Ships are used to transport commodities or people. More than 95 % of all ships still use diesel engines for driving [1]. However, the usage of diesel engines contributes annually to around 2.5 % of global warming and about 1000 million tons of CO_2. At the same time, it is well known that fossil fuels contribute to 85 % of all existing energy and represent the most common source of electrical power [2]. The lack of such monohull ships lies in the lack of transverse angle stability, and a smaller deck area [3]. So, from this problem, this study chose the Catamaran ship, where on the Catamaran ship there are two hulls, and high stability allows for the occurrence of a very small capsized ship.

According to data from research, it is known that the average value of wind speed is 4 m/s to 10 m/s and the intensity of sunlight reached 4.8 kWh/m^2/day up to 7.2 kWh on average, with a monthly variation of roughly 9 % [4, 5]. From these two data, it can be said that some areas of the sea have energy sources that are not limited to wind energy and solar energy.

The Catamaran ship model is used in the research to examine the potential utilization of certain renewable energy source controls. The Catamaran model's battery powers the BLDC (Brush Less Direct Current) motor. Two PV modules are used to charge the battery. They are specified to be 100 Wp per 0.5-meter square PV. Additionally, to get kinetic energy, BLDC motor is used to propel the Catamaran itself.

From the problems above, this research was carried out to utilize renewable energy sources, namely wind and solar energy; and reduce fuel use. In addition, determining the parameter value of the actuator and sensor for the controller is also a challenge, because, if the parameter value changes it will cause the control reading results to change as well. Therefore, study that devoted using PID-N control, which has a systematic and fast design are scientifically relevance.

2. Literature review and problems statement

A Catamaran ship is a twin-hull ship [6, 7]. The two hulls of a Catamaran ship are joined by a robust deck structure, which stretches on them to endure significant bending moments and shear stresses and surge the ship toward its midline (Centerline) design [8, 9]. The ship's specification has a 170 cm length of the arc, 100 cm beam, and 32 cm depth. The ship's weight is 39.1 kg. Compared to monohull ship types, Catamaran ships deal with less resistance because of the lower draft [10], but one disadvantage of Catamaran usage is that due to the thin shape of the hulls, the seakeeping qualities (heave and pitch motions) are comparable to monohull ships [11, 12].

The Catamaran is equipped with 2 propellers placed at the lower end of the rear ship, besides that the propeller is used as a Catamaran propulsion. In a propeller equipped with a BLDC motor, the BLDC motor stator is formed from windings, which allows the magnetic poles to shift depending on the polarity of the stator winding current while the rotor consists of permanent magnets, keeping the poles stationary [13]. With the removal of brush and commutator parts, this motor has advantages including increased efficiency, reduced noise generated when rotating, cheaper maintenance, and can rotate at high speed due to reduced friction with the brush. While the disadvantages of this motorcycle are more complicated to control and more expensive [14]. To adjust the rotational speed of the propeller used 2 ESC (Electronic Speed Control) drivers. ESC generates a three-phase square wave or trapezoidal PWM (Pulse Width Modulation) signal for the motor [15]. The ESC will be controlled by a microcontroller to regulate the rotational speed of the BLDC motor, and the results of the control will be used as Catamaran propulsion. In addition to the propeller, the Catamaran is also equipped with a speed sensor, to determine the speed of the Catamaran and as a feedback value for the PID-N (Proportional, Integral, and Derivative – Filter Coefficient) controller. The attachment of the speed sensor is 45 degrees below the deck.

Systems of control that are Proportional, Integral, and Derivative (PID). These control systems each have some benefits. Since oscillations will result from the output created by the proportional control system's sluggish response time and integral control's advantage of reducing error rise time, it is necessary to utilize derivative control, which has the advantage of lowering errors or lowering overshot/undershot. Because of this, it is possible to combine these three control actions into a PID control action to create output with a quick rise in time and error. The P, I, and D controller parts work together to quicken a system's response by eliminating offsets and causing significant initial changes [16]. To reduce the complexity of tuning PID [17]. It is crucial to study and to prove empirically to identify the robust performance of PID-N in controlling the speed of Catamaran ships applying BLDC motor propeller.

3. The aim and objectives of the study

The aim of this study is to develop a PID control model for the speed stability of electric energy Catamaran ships using two BLDC motors for the rotation of its two propellers.

To achieve this aim, the following objectives have been established:

– to identify the effectiveness of ship speed settings using PID-N control on Catamaran speeds stability without payload and with payload empirically;

– to determine the ratio of power toward speed of the Catamaran ships model.

4. Materials and methods of research

4. 1. Object and hypothesis of the study

To obtain the most effective design method, PID-N is used, where with the addition of filter coefficients (N) derivatives can map different PID parameterizations with predetermined PID parameters, so that it can be used as scheduled gains in PID control. The advantage of this method is that this system considers the physical system being modeled as a black box, so that whatever type of components exist in the physical system and any type of material does not need to be considered [8]. PID-N was therefore determined as the proposed method, which made it easier for control designers to quickly change the performance of PID control, and making it possible to apply PID-N to Catamaran speed stability with payload and without payload. By using PID-N control, it is expected that speed control on Catamarans, which use BLDC propeller actuator loads, can have robust performance control of expected speed changes and changing payloads. By this study, it is expected that Catamaran propeller control using BLDC using PID-N is one of the most appropriate control alternatives.

4. 2. Control Diagram

The ship speed control method is used to adjust the speed of the ship so that the speed of the ship is under the set point, as shown in Fig. 1

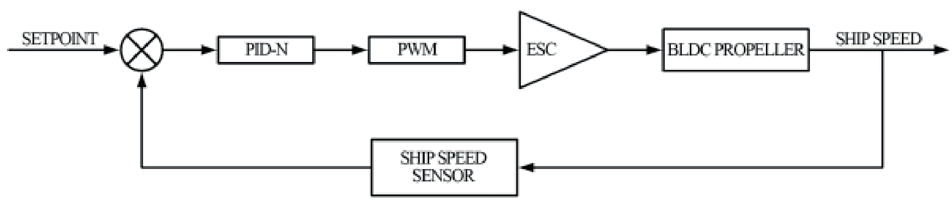


Fig. 1. Ship speed control design

In Fig. 1, ship speed is used as an input for ship speed control, if the ship's speed is less than the setpoint, then the propeller will be controlled by PID-N to accelerate propeller rotation. If the ship's speed is more than the set point, then the propeller will be controlled by PID-N to slow down the propeller rotation speed. The ship's speed sensor is used to read the ship's speed and is also used for feedback.

4. 3. Plant identification

The obtained mathematical model or plant model will be used for simulation. So that it is possible to design control in a simulated manner without having to harm the actual system.

From the identification of RLS, several parameter values are obtained that are useful for forming discrete switching functions. They are a_1, a_2, b_1, and b_2. So that it can form a discrete transfer function by entering the following:

$$Plantz(z)=\frac{b_1 z+b_2}{z^2+a_1 z+a_2}=\frac{y(z)}{u(z)}.$$

The test is carried out by inputting a stepping signal. In the test, graphic results such as Fig. 2 were obtained.

In Fig. 2, the reading results of the input step function graph are shown on the red line, for the response of the step function is shown on the blue line. Achieving settling time takes 0.25 seconds.

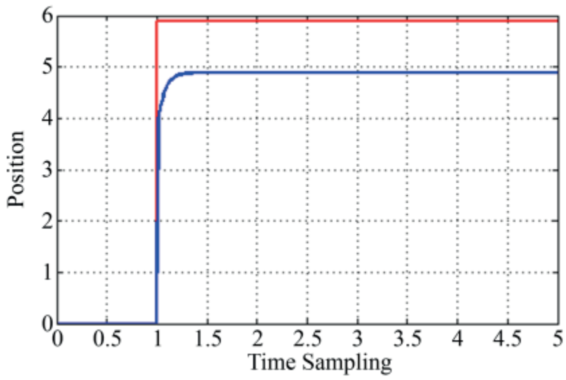


Fig. 2. Transfer function identification

4. 4. PID-N control

Then a simulation is carried out to control the plant so that changes in the values of KP, KI, and KD can be made without having to do calculations to find the transfer function of the control. Simulated plant model, as shown in Fig. 3.

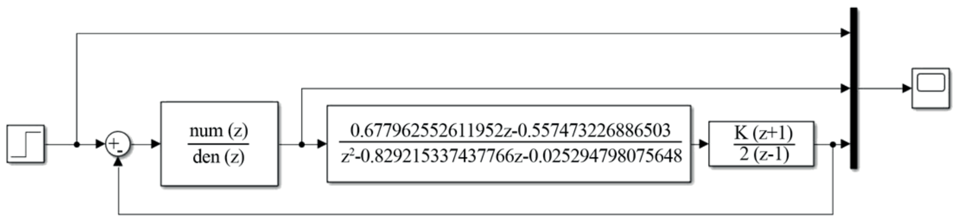


Fig. 4. Comparing the tuning results with the transfer function

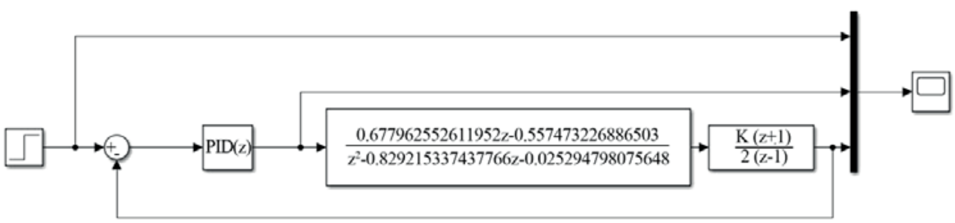


Fig. 3. PID-N

During the PID Tunning process, the Transfer function plan is read in a Close loop and calculates KP, KI, and KD. so that it only needs to be tunning so that the plant response works as expected. after the tunning process is complete, Control PID will automatically change the values of KP, KI, and KD.

4. 5. Implementation of the algorithm on a microcontroller

In the implementation on the microcontroller domain Z or discrete must be transformed into different equations. To get the discrete transfer function, it is necessary to enter the values a_1, a_2, a_3, b_1, b_2, and b_3 in (1):

$$Control(z)=\frac{b_1z^2+b_2z+b_3}{a_1z^2+a_2z+a_3}=\frac{U(z)}{E(z)}, \tag{1}$$

$$b_1=K_p(1+NT_s)+K_iT_s(1+NT_s)+K_dN,$$

$$b_2=-\left(K_p(2+NT_s)+K_iT_s+2K_dN\right),$$

$$b_3=K_p+K_dN,$$

$$a_1=1+NT_s,$$

$$a_2=-(2+NT_s),$$

$$a_3=1.$$

After getting a discrete transfer function, it is necessary to test whether the transfer function discrete control made is in accordance to the plant or not, as shown in Fig. 4.

Once the Equation is discrete and the plant has the same response. Then discrete transfer equation can be converted into a different equation by entering a_1, a_2, a_3, b_1, b_2, b_3 into the equation:

$$U[k]=\frac{\begin{pmatrix} b_1*E[k]+b_2*E[k-1]+b_3* \\ *E[k-2]-a_2*U[k-1]-a_3*U[k-2]\end{pmatrix}}{a_1}.$$

The equation above is a transfer function of the parameters *Kp*, *Ki*, and *Kd*.

5. The results of the research on the Catamaran ships using PID-N control

5. 1. The results of ship speed with PID-N method

The results of ship speed with a setpoint of 0.4 m/s. Fig. 5 is the result of the Catamaran ship experiment applying the BLDC propeller and ship speed sensor.

From Fig. 5, the data variable taken are speed setting 0.4 m/s, ship speed, and power BLDC propeller for every second, without payload; in which the ship's weight is 39.1 kg.

Fig. 6 is the result of the Catamaran ship experiment applying the BLDC propeller and ship speed sensor.

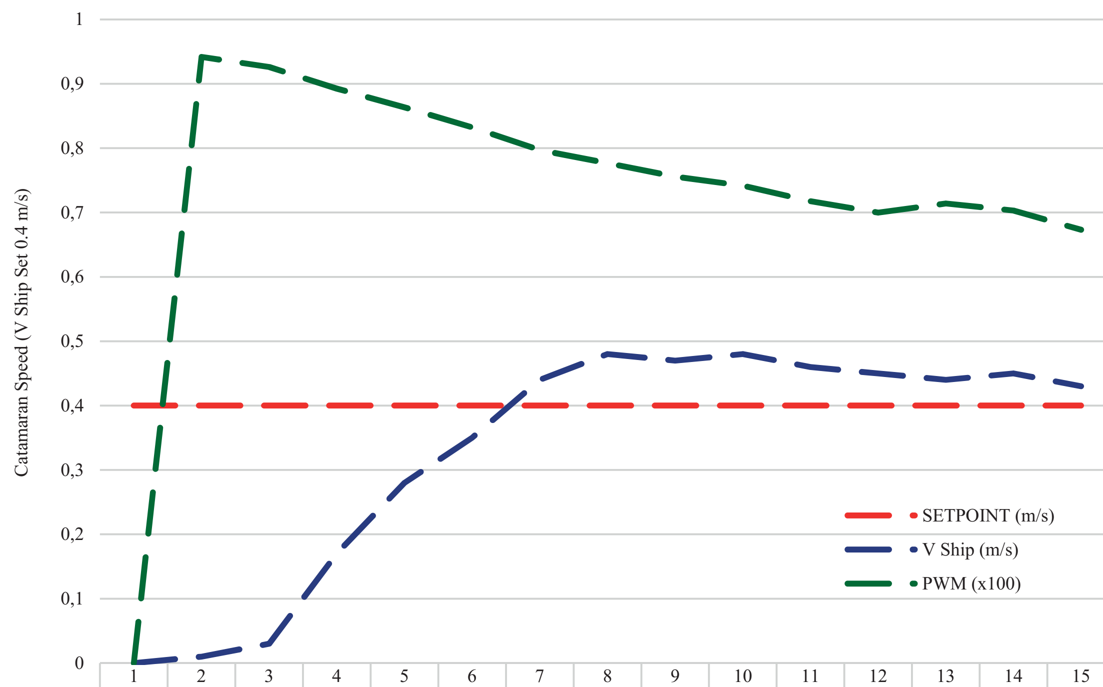
From Fig. 6, the data variable taken are speed setting 0.4 m/s, ship speed, and power BLDC propeller for every second, without payload; in which the ship's weight is 39.1 kg+6.4 kg. Table 1 is the performance of ship speed toward different payloads.

In Table 1, the ships speed toward different payloads; no payload (39.1 kg) and with payload (39.1 kg+6.4 kg) for 0.4 m/s speed. The table descended toward time per second.

The results of ship speed with setpoint 0.5 m/s. Fig. 7 is the result of the Catamaran ship experiment applying the BLDC propeller and ship speed sensor.

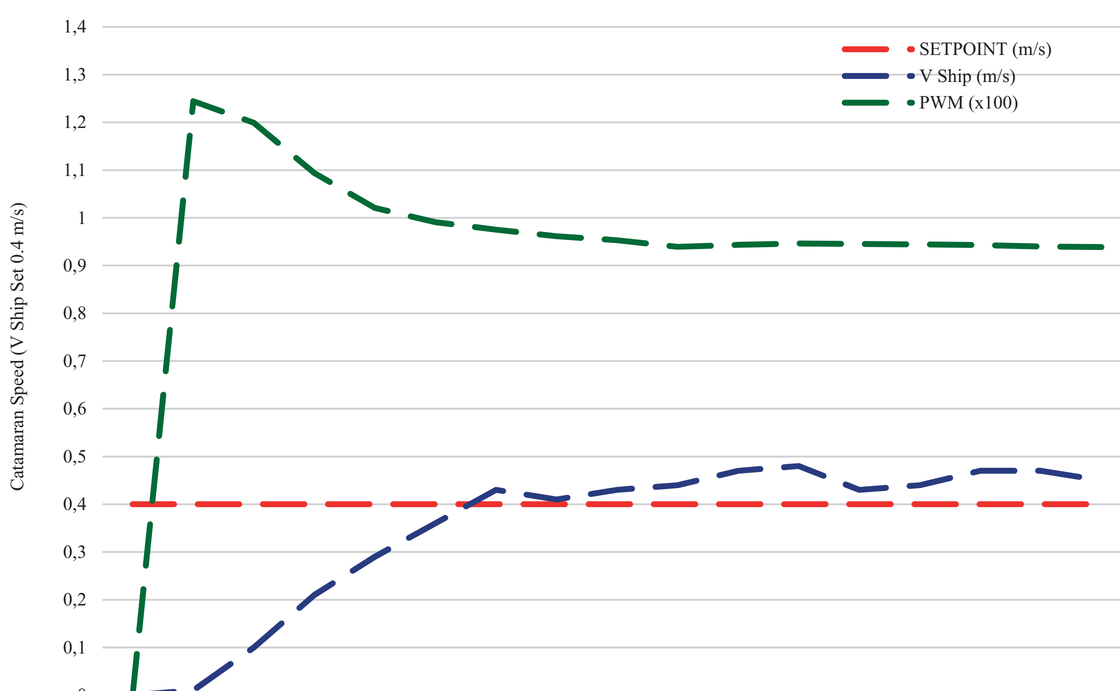
From Fig. 7, the data variable taken were speed setting 0.5 m/s, ship speed, and power BLDC propeller for every second, without payload; in which the shipping weight is 39.1 kg.

Fig. 8 is the result of the Catamaran ship experiment applying the BLDC propeller and ship speed sensor.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SETPOINT (m/s)	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4
V Ship (m/s)	0	0,01	0,03	0,17	0,28	0,35	0,44	0,48	0,47	0,48	0,46	0,45	0,44	0,45	0,43
PWM (x100)	0	0,9419	0,9262	0,8926	0,8635	0,8323	0,7972	0,7766	0,7559	0,7417	0,7176	0,6999	0,7141	0,703	0,6733

Fig. 5. Control performance on the ship without payload (ship weight 39.1 kg)



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
SETPOINT (m/s)	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4
V Ship (m/s)	0	0,01	0,1	0,21	0,29	0,36	0,43	0,41	0,43	0,44	0,47	0,48	0,43	0,44	0,47	0,47	0,45
PWM (x100)	0	1,2445	1,199	1,094	1,0207	0,9909	0,9751	0,9614	0,9531	0,9394	0,9432	0,9465	0,9455	0,9443	0,9431	0,9401	0,9388

Fig. 6. Control performance on the ship with payload (ship weight 45.5 kg)

Table 1

Propeller motor response to ship speed sensor with setpoint 0.4 m/s

Time (s)	Setpoint (m/s)	No Payload 39.1 kg		With Payload 45.5 kg	
		Ship Speed (m/s)	Error (m/s)	Ship Speed (m/s)	Error (m/s)
1	0	0	0	0	0
2	0.4	0.01	0.39	0.01	0.39
3	0.4	0.03	0.37	0.1	0.3
4	0.4	0.17	0.23	0.21	0.19
5	0.4	0.28	0.12	0.29	0.11
6	0.4	0.35	0.05	0.36	0.04
7	0.4	0.44	0.04	0.43	0.03
8	0.4	0.48	0.08	0.41	0.01
9	0.4	0.47	0.07	0.43	0.03
10	0.4	0.48	0.08	0.44	0.04
11	0.4	0.46	0.06	0.47	0.07
12	0.4	0.44	0.04	0.43	0.03

From Fig. 8, the data variable taken were speed setting 0.5 m/s, ship speed, and power BLDC propeller for every second, without payload; in which the shipping weight is 39.1 kg+6.4 kg. Table 2 is the performance of ship speed toward different payloads.

In Table 2, the ships speed toward different payloads; no payload (39.1 kg) and with payload (39.1 kg+6.4 kg) for 0.5 m/s speed. The table descended toward time per second.

Table 2

Propeller motor response to ship speed sensor with setpoint 0.5 m/s

Time (s)	Setpoint (m/s)	No Payload 39.1 kg		With Payload 45.5 kg	
		Ship Speed (m/s)	Error (m/s)	Ship Speed (m/s)	Error (m/s)
1	0	0	0	0	0
2	0.5	0.01	0.49	0.01	0.49
3	0.5	0.16	0.34	0.07	0.43
4	0.5	0.39	0.11	0.2	0.3
5	0.5	0.52	0.02	0.31	0.19
6	0.5	0.56	0.06	0.38	0.12
7	0.5	0.57	0.07	0.42	0.08
8	0.5	0.58	0.08	0.44	0.06
9	0.5	0.57	0.07	0.48	0.02
10	0.5	0.58	0.08	0.48	0.02
11	0.5	0.55	0.05	0.51	0.01
12	0.5	0.53	0.03	0.52	0.02
13	0.5	0.52	0.02	0.51	0.1
14	0.5	0.51	0.01	0.49	0.1
15	0.5	0.53	0.03	0.51	0.1

The results of ship speed with setpoint 0.6 m/s. Fig. 9 is the result of the Catamaran ship experiment applying the BLDC propeller and ship speed sensor.

From Fig. 9, the data variable taken were speed setting 0.6 m/s, ship speed, and power BLDC propeller for every second, without payload; in which the shipping weight is 39.1 kg.

Fig. 10 is the result of the Catamaran ship experiment applying the BLDC propeller and ship speed sensor.

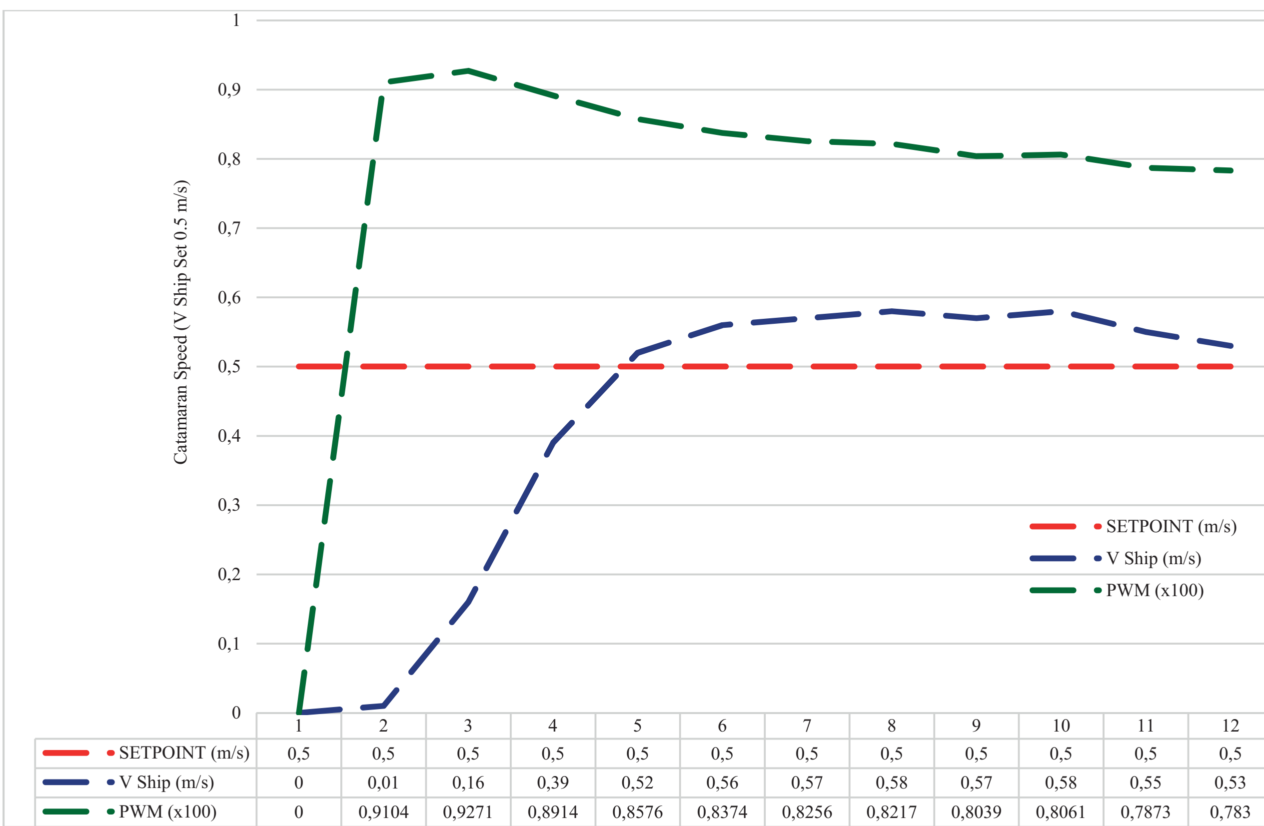
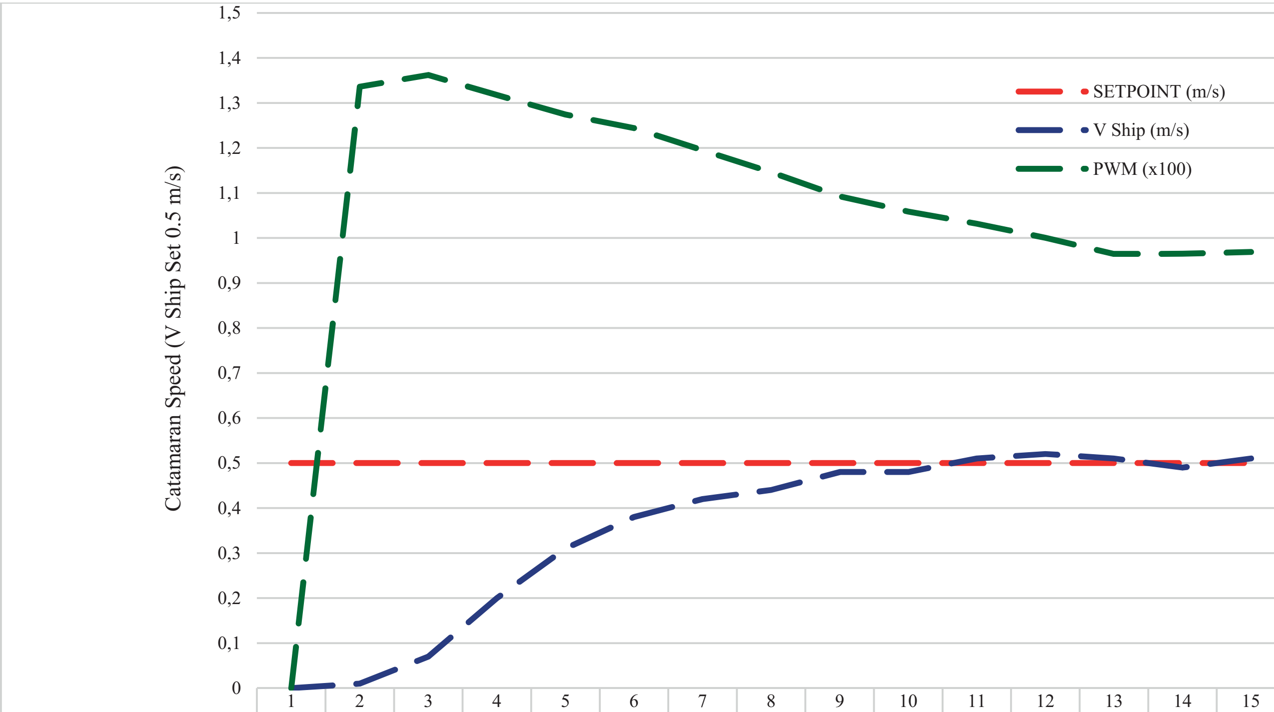
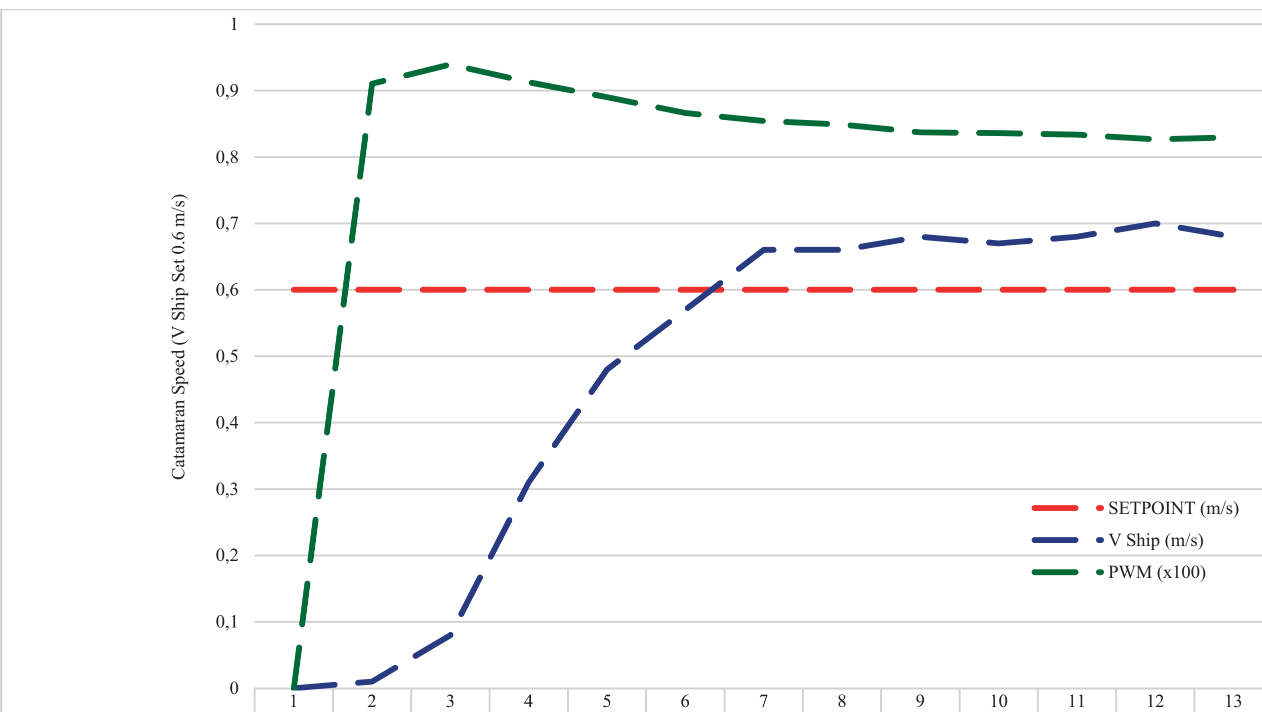


Fig. 7. Control performance on the ship without payload (ship weight 39.1 kg)



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SETPOINT (m/s)	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5
V Ship (m/s)	0	0,01	0,07	0,2	0,31	0,38	0,42	0,44	0,48	0,48	0,51	0,52	0,51	0,49	0,51
PWM (x100)	0	1,336	1,3622	1,3175	1,2744	1,2442	1,1951	1,146	1,0924	1,0588	1,0316	1,0005	0,9646	0,9649	0,9688

Fig. 8. Control performance on the ship with payload (ship weight 45.5 kg)



	1	2	3	4	5	6	7	8	9	10	11	12	13
SETPOINT (m/s)	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6
V Ship (m/s)	0	0,01	0,08	0,31	0,48	0,57	0,66	0,66	0,68	0,67	0,68	0,7	0,68
PWM (x100)	0	0,9104	0,9394	0,9125	0,8901	0,8662	0,8543	0,8489	0,837	0,836	0,8336	0,8266	0,8297

Fig. 9. Control performance on the ship without payload (ship weight 39.1 kg)

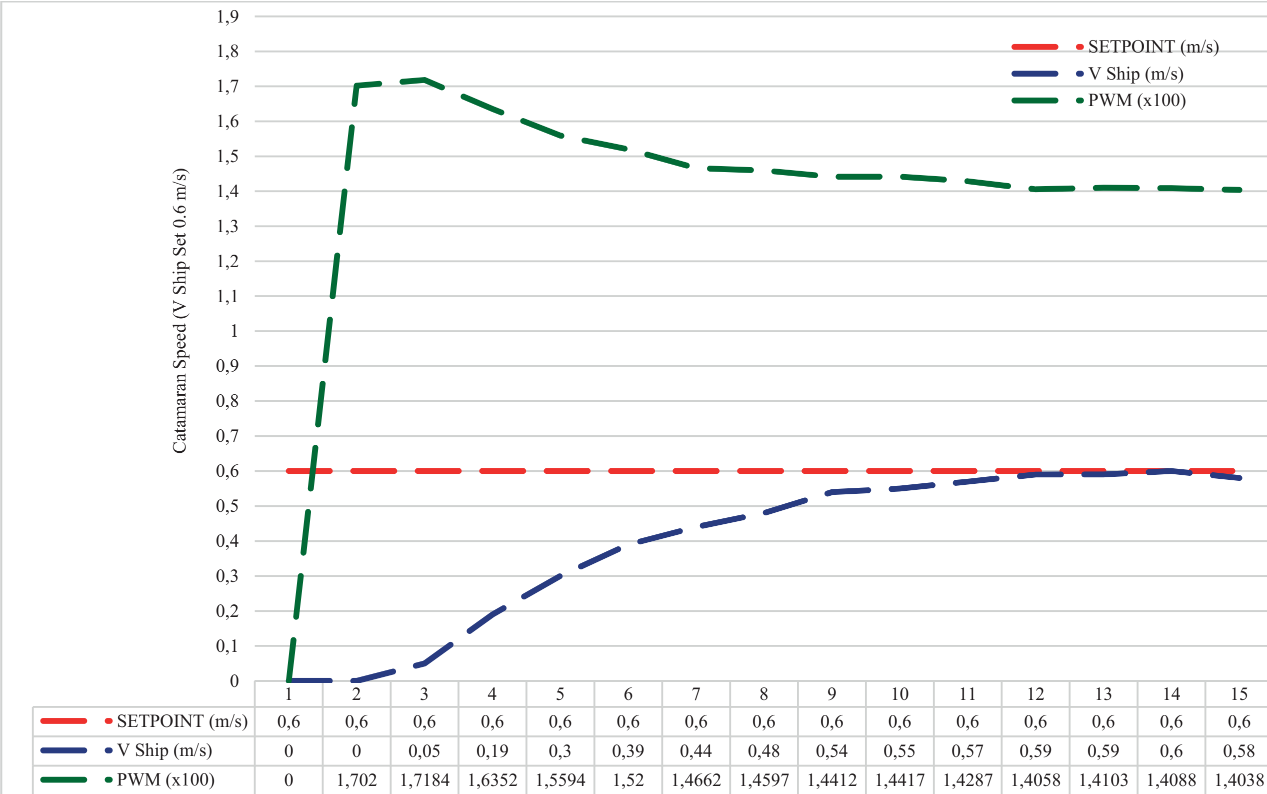


Fig. 10. Control performance on the ship with payload (ship weight 45.5 kg)

From Fig. 10, data variables taken were speed setting 0.6 m/s, ship speed, and power BLDC propeller for every second, without payload; in which the shipping weight is 39.1 kg+6.4 kg. Table 3 is the performance of ship speed toward different payloads.

Table 3

Propeller motor response to ship speed sensor with setpoint 0.6 m/s

Time (s)	Setpoint (m/s)	No Payload 39.1 kg		With Payload 45.5 kg	
		Ship Speed (m/s)	Error (m/s)	Ship Speed (m/s)	Error (m/s)
1	0	0	0	0	0
2	0.6	0.01	0.59	0	0.6
3	0.6	0.08	0.52	0.05	0.55
4	0.6	0.31	0.29	0.19	0.41
5	0.6	0.48	0.12	0.3	0.3
6	0.6	0.57	0.03	0.39	0.21
7	0.6	0.66	0.06	0.44	0.16
8	0.6	0.66	0.06	0.48	0.12
9	0.6	0.68	0.08	0.54	0.02
10	0.6	0.67	0.07	0.55	0.05
11	0.6	0.68	0.08	0.57	0.03
12	0.6	0.7	0.1	0.59	0.01
13	0.6	0.68	0.08	0.59	0.01
14	0.6	0.65	0.05	0.6	0.00
15	0.6	0.66	0.06	0.58	0.02

In Table 2, the ships speed toward different payloads; no payload (39.1 kg) and with payload (39.1 kg+6.4 kg) for 0.6 m/s speed. The table descended toward time per second.

5. 2. Electric power for BLDC motor toward speed

Fig. 11 is the percent average electric power obtained from the three-speed setting.

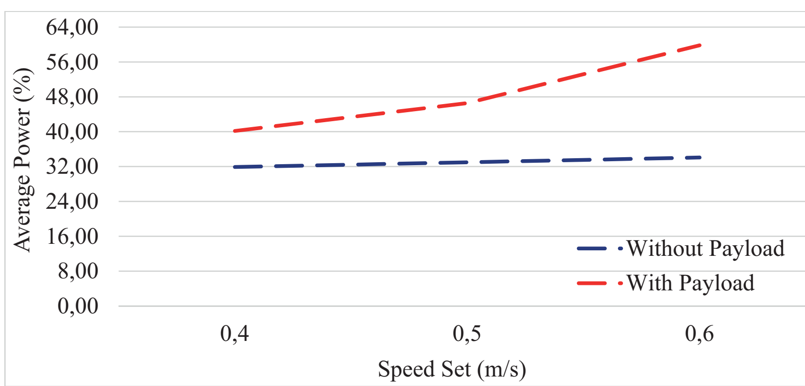


Fig. 11. Average electric power toward speed setting

The Fig. 11 shows that the faster the speed setting, the higher the average electric power required. The heavier the Catamaran, the higher the average electric power required. Average power (%) is $\overline{\%Power} = \dfrac{\sum_{t=0}^{t=12} \dfrac{100 * Y_{(t)}}{255} * 100\,\%}{t}$,

$Y_{(t)} = PWM_{(t)}$ from data Fig. 5 until Fig. 10.

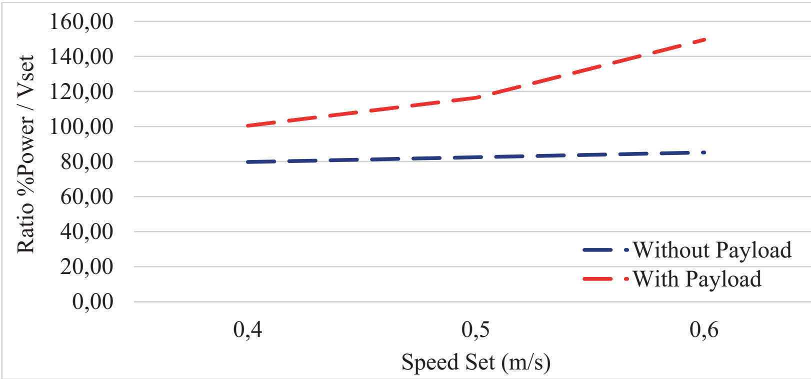


Fig. 12. Ratio electric power toward speed setting

Fig. 12, shows the ratio of average electric power toward speed setting for the three-speed. The ratio obtained from average power (%) is divided by speed setting, and the formula is:

$$Ratio = \frac{\overline{\%Power}}{V_{Set}}.$$

6. Discussion of the result of control PID-N in ship speed

Catamaran ship with no payload has a set speed reached 7 seconds, a maximum overshoot of 20 % (Fig. 5). As for ships with a payload have a set speed reached 11 seconds, a maximum overshoot of 20 % (Fig. 6). In Table 1 when ship speed reached rise time at 7 seconds, the Catamaran ship without payload, has an error speed of 0.04 m/s, while the Catamaran ship with payload has an error speed of 0.03 m/s. The average error speed of a Catamaran ship without payload when stable is 0.061 m/s and the average error speed of a Catamaran ship with payload when stable is 0.035 m/s.

The green colored lines of Fig. 5 and Fig. 6, are the electric power given to two-unit propellers for the BLDC motor, which is the percent of power: $\frac{100 * Y_{(t)}}{255} * 100\,\%$. The data is the duration of PWM sampling per second generated by the PID-N output. From both images, it can be seen that there is the highest power (36.93 % without payload for Fig. 5 and 48.8 % with payload for Fig. 6), then decreases it is necessary to rotate the BLDC propeller motor the first time. After activating the BLDC propeller, the motor will decrease and stable its energy use, because the speed of the Catamaran is in accordance with the setpoint (0.4 m/s). Average electric power without payload is 31.89 %, but with payload is 40.17 %.

Fig. 7, is when Catamaran ships with no payload setting speed reached 5 seconds, the maximum overshoot of 16 %. Ships with payload have setting speed reached 11 seconds, maximum overshoot of 4 % (Fig. 8). In Table 2, when the shipping speed reached rise time at 5 seconds, the Catamaran ship without payload, has an error speed of 0.08 m/s, while the Catamaran ship with payload reached rise time at 11 seconds, has an error speed of 0.08 m/s. Average error speed of a Catamaran ship without a payload when stable is 0.06 m/s and the average error speed of a Catamaran ship with a payload when stable is 0.066 m/s.

The green colored lines of Fig. 7, 8, it can be seen that there is a high-power peak (35.7 % without a payload for Fig. 7 and 52.39 % with payload for Fig. 8) then decreases it is necessary to activate the BLDC propeller motor the first time after active the BLDC propeller motor will decrease and stable its energy use because the speed of the Catamaran is in accordance with the setpoint (0.5 m/s). Average electric power without payload is 32.98 %, but with payload is 46.56 %.

From Fig. 9, when a ship with no payload has a set speed reached at 7 seconds, the maximum overshoot of 16.67 %. Ships with payload have setting speed reached at 14 seconds, maximum overshoot of 0 % (Fig. 10). In Table 3, when the shipping speed reached rise time at 7 seconds, the Catamaran ship without payload, has an error speed of 0.06 m/s, while the Catamaran ship with payload reached rise time at 14 seconds, has an error speed of close to zero. The average error speed of a Catamaran ship without payload when stable is 0.071 m/s and the average error speed of a Catamaran ship with payload when stable is 0.01 m/s.

The green-colored lines of Fig. 9, 10, It can be seen in the green-colored lines of Fig. 9, 10 that there is a high-power peak (35.7 % for Fig. 9 and 66.74 % for Fig. 10) then decreases it is necessary to activate the BLDC propeller motor the first time after active the BLDC propeller motor will decrease and stable its energy use because the speed of the Catamaran is in accordance with the setpoint (0.6 m/s). Average electric power without payload is 34.06 %, but in with payload is 59.82 %.

From Fig. 11, it can be concluded that the change in power to the addition of speed setting follows the exponential formula using the quadratic method, and the resulting formula, $Ratio = 895.5 * V_{Set}^2 - 613 * V_{Set} + 208.5$ with payload, while for without payload in the formula, $Ratio = -1 * V_{Set}^2 - 28.2 * V_{Set} + 68.6$.

From Fig. 12, it can be concluded that the change in the ratio of power to speed gain follows the exponential formula using the quadratic method, and the resulting formula, $\%Power = 343.5 * V_{Set}^2 - 245.25 * V_{Set} + 83.31$ with payload, while for without payload in the formula, $\%Power = -0.5 * V_{Set}^2 + 11.35 * V_{Set} + 27.43$.

Most industrial processes include varying degrees of nonlinearity, parameter variability, and uncertainty in the mathematical model of the system, making adjusting PID control parameters complex, and obtaining the ideal state under field conditions in actual production difficult [8]. On the other hand, the PID-N of this research shows robust performance, systematic, and easy design. The advantage of using a PID-N controller is the addition of derived filter coefficients to map different PID parameterizations to predefined PID parameters so that they can be used as predefined advantages in PID controls. The use of PID-N in this control system is coupled with anti-windup and is very functional for Catamaran ship controller using payload and without payload, so that in this study, PID-N design makes it easier for control designers to change control performance of PID-N quickly.

The difficulty in this study is the lack of a testing site, so that, it is not known when to reach the rise time so that direct testing is needed at sea, but from the testing that has been done can get the time needed to reach the rise time and the maximum overshoot value.

7. Conclusions

1. The fastest time to reach the setting speed is 6 seconds when the Catamaran ship without payload (ship weight 39.1 kg) uses a setpoint of 0.4 m/s but has a maximum overshoot of 0.08 m/s. The smallest error value obtained is 0.02 m/s, when the Catamaran ship with payload (ship weight 45.5 kg) uses a setpoint of 0.6 m/s, and has a maximum overshoot value of 0.00 m/s. It is proven that the PID-N control can eliminate tuning gain time and give significant results, making it technically and commercially acceptable.

2. Ratio percent power toward variate speed setting without payload follow the formula:

$$\%Power = -0.5 * V_{Set}^2 + 11.35 * V_{Set} + 27.43;$$

and with payload follow the formula:

$$\%Power = 343.5 * V_{Set}^2 - 245.25 * V_{Set} + 83.31.$$

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship, or otherwise, that could affect the research and its results presented in this paper.

Financing

This research has been carried out under the support of Higher Education, the Ministry of Education and Culture of Indonesia in 2022, through the Magister Thesis Research scheme, which was funded by the Internal independent budget *Politeknik Negeri Malang*.

Data availability

The manuscript has no related data.

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