Kinetik: Game Technology, Information System, Computer Network, Computing, Electronics, and Control
Journal homepage: http://kinetik.umm.ac.id
ISSN: 2503-2267
Vol. 8, No. 4, November, Pp. 741-750

PID controller implementation on animal experimental treadmill for heart medicine purpose

Melinda Melinda*[1], Muhammad Ridwan[2], Cut Nanda Nurbadriani[1], Yunidar Yunidar[1]
Department of Electrical and Computer Engineering, Universitas Syiah Kuala, Banda Aceh, Indonesia[1]
Department of Cardiology and Vascular Medicine, Faculty of Medicine, Universitas Syiah Kuala, Banda Aceh, Indonesia[2]

Article Info
Keywords:
Treadmill, Speed Motor DC, PID Controller, Heart Medicine

Article history:
Received: June 24, 2023
Accepted: September 11, 2023
Published: November 30, 2023

Cite:
Melinda, M. Ridwan, C. N. Nurbadriani, and Yunidar, "PID Controller Implementation on Animal Experimental Treadmill for Heart Medicine Purpose", KINETIK, vol. 8, no. 4`, Nov. 2023.
https://doi.org/10.22219/kinetik.v8i4.1762

*Corresponding author.
Melinda
E-mail address:
melinda@usk.ac.id

Abstract
Experimental animals such as rats are often used for medical research and therapy, such as cardiologists who use a special treadmill to measure the heart health of rats by training walking or running in order to determine the appropriate dose for individuals before being applied to their patients. This research designed a system that is operated by the speed of a DC motor. To control the system, it is proposed to implement a Proportional Integral Derivative (PID) control that is able to stabilize the rotation of the DC motor based on the BPM value recorded by the encoder sensor. The value is used as feedback to the PID control, so that it can control the speed of the DC motor and work optimally and stably under load or no load. Adding a limit switch as a fatigue zone to determine the final duration. This system was tested on several objects, namely 4-month-old rats with a mass of 211 grams, 224 grams, 230 grams, and 240 grams and 2-month-old rats with a mass of 24 grams, 27 grams, 28 grams, and 30 grams. The results show that the speed reading using PID control is in accordance with the constants Kp = 17, Ki = 7, and Kd = 1. This test has a percentage overshoot (%) of 5% and an average rise time value of 0.14 seconds. System performance with a percentage accuracy of 90% starting from a setpoint of 35 m/min.

1. Introduction

The development in the field of heart health is increasingly sophisticated by using technology to diagnose diseases and their treatment [1-6]. The heart is an important organ in knowing the health of a person's body because it affects the body's metabolism [7]. Maintaining and avoiding heart disease can be done by exercising, such as using a treadmill that can trigger muscle movement to launch the body's metabolism and nourish the body, especially the heart. In the medical world, cardiologists will provide heart exercises using a treadmill to patients to determine the ability or health of a patient's heart with different doses for each individual, but medical experts must conduct research first to avoid unwanted things. The health research code of ethics explains that one of the basic principles in conducting research in the biomedical field involving humans must follow scientific provisions and be based on laboratory testing of appropriate experimental animals and adequate knowledge from literature studies [8].

Experimental animals that are often used in research are albino white rats that are able to respond quickly and provide a scientific picture that may occur in humans because their anatomical structures are similar to humans. Based on the guidelines in providing exercise in rats using exercise equipment that has duration and frequency categories and the use of experimental animals must follow applicable physical exercise [9]. The use of treadmills as well as in humans, rats can also be observed for their heart rate and heart health. This observation requires a special rat treadmill device that will determine the health of the rat's heart. Therefore, a special treadmill for albino rats is needed to determine the dose of exercise ability. The device that has been designed can be placed on a sturdy and stable treadmill stand. All these conditions can provide a standardized environment for exercising rats. However, the available devices use a manual system to measure duration and control speed [2].

This study proposes a PID (Proportional Integrative Derivative) control method that can be used to control the speed of a DC motor on a treadmill. PID is a closed-loop circuit that can reduce the error value by obtaining the PID constant values (Kp, Ki, and Kd) of a system so that the system can run according to the setpoint [10]. Several studies had utilized PID control to control the speed of DC motor regulator systems on MATLAB-based mini conveyors [11]. The constant values obtained are Kp = 0.9, Ki = 51.4, and Kd = 0.01. This study aimed to create an albino rat treadmill that provides space to follow the movement of the belt given the speed driven by the DC motor, the encoder sensor records the speed of the DC motor, the limit switch determines the duration of the exercise, and the value is displayed on the 20x4 LCD. Hence, the contributions of this study are:

- The tool is specially designed for albino rats with various body weights.

- Utilizing PID control with a constant value so that this tool works stable even with a load under certain setpoint speed.
- Using additional tools to determine the exercise time automatically.

The effect of using PID to control the speed of the rat-specific treadmill is that it can provide precise information in detecting the rat's heart rate. This utilization is generated by determining the speed and duration of exercise given to experimental animals, then the exercise dose that can be used by humans to determine heart health based on the age equivalence of the albino rats used.

2. Related Work

This supports research related to this study in determining the use of tools, materials, and methods. In addition, researchers have sufficient knowledge to produce the latest innovations. The use of rats in research with various important parameters studied in rats for various research purposes, namely drug trials for lung health [12], rat body health (rat body weight, resting heart rate and skeletal muscle fiber type composition) [13], drug administration testing for neurological diseases [14], running ability of rats using a treadmill [15], effects of vaccine administration [16], [17]. All these studies were conducted by providing exercise using a treadmill. For the manufacture of this rat treadmill has several provisions that are commonly used in conducting research, namely the determination of belt inclination, treadmill speed, rat mass and test duration. As in the previous research [17] which used an incline on the treadmill of 32˚ with a speed of 18 m/min using rats with a mass of 200-300 g for 2 hours.

Related research by D. Irawan [18], who designed the treadmill hardware and Code Vision AVR (CVAVR) software using the "hex" language. The tool for body fitness is utilized based on a microcontroller, controlled using buttons, and displays the speed value on the LCD screen. The speed displayed on the LCD is obtained from the speed of the DC motor on the treadmill. So, it is required to control the speed value of the treadmill using a PID controller. The DC motor has a large initial rotation and causes disturbances in the stability of the system [19]. It requires suppression of overshoot with a low time value. As in the research conducted by Rosalina [20], using the PID control method to reduce overshoot at the beginning of the DC motor rotation, control is done by combining the constant values of Kp, Ki, and Kd. The PID control output is obtained with a rise time of 0.1 s, a settling time of 0.6 s, and a peak time of 0.2 s with a stable duration of 2.3 s. In the following year, F. Suryatini [21] developed a method to stabilize when the DC motor is in high order. DC motor settings using the value of P, PI, and PID with the Ziegler Nichols method. The constant values used are Kp = 175.44, Ki = 4408.22, and Kd = 1.746. So, the result of the steady-state error is 0%, the rise time is 0.00467 s, the settling time is 0.0404 s, and the overshoot is 9.9%. The next development carried out in this study is based on related research, namely, using the PID control method on DC motor speed regulation. Thus, the tool works with a stable system and produces information that can be used for health.

3. Design and Material

3.1 Design of Prototype

In this study, the treadmill design provides a space for exercising mice using wood, acrylic, 4 rolling bars, and a belt. The components used to control the system, as shown in Figure 1, are the 3D experimental animal treadmill design, namely a rotary encoder sensor for recording the speed of the DC motor, a DC motor as the main drive on the treadmill, a limit switch sensor that determines the duration of the exercise, and a 20x4 LCD displaying the speed and duration time. This tool has a length of 70 cm, a width of 20 cm, a room height of 10 cm, and a more detailed size of each side can be seen in Figure 2 in units of mm (millimeters). Figure 2(a) shows the size of the side of the treadmill, Figure 2(b) shows the size of the top of the treadmill, and Figure 2(c) shows the size of the back of the treadmill. They are put together in one unit so that the system can work. The equipment and materials required are as shown in Table 1 and Table 2.

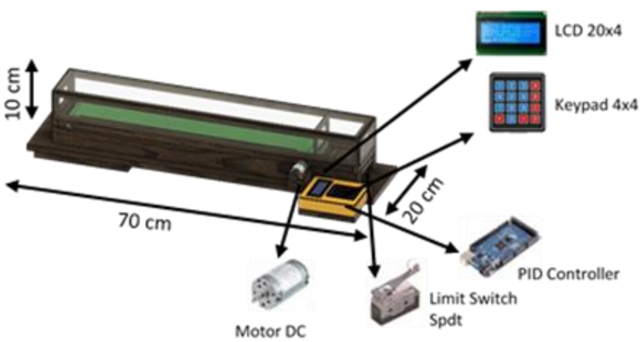

Figure 1. 3D sketch of a Trial Animal Treadmill

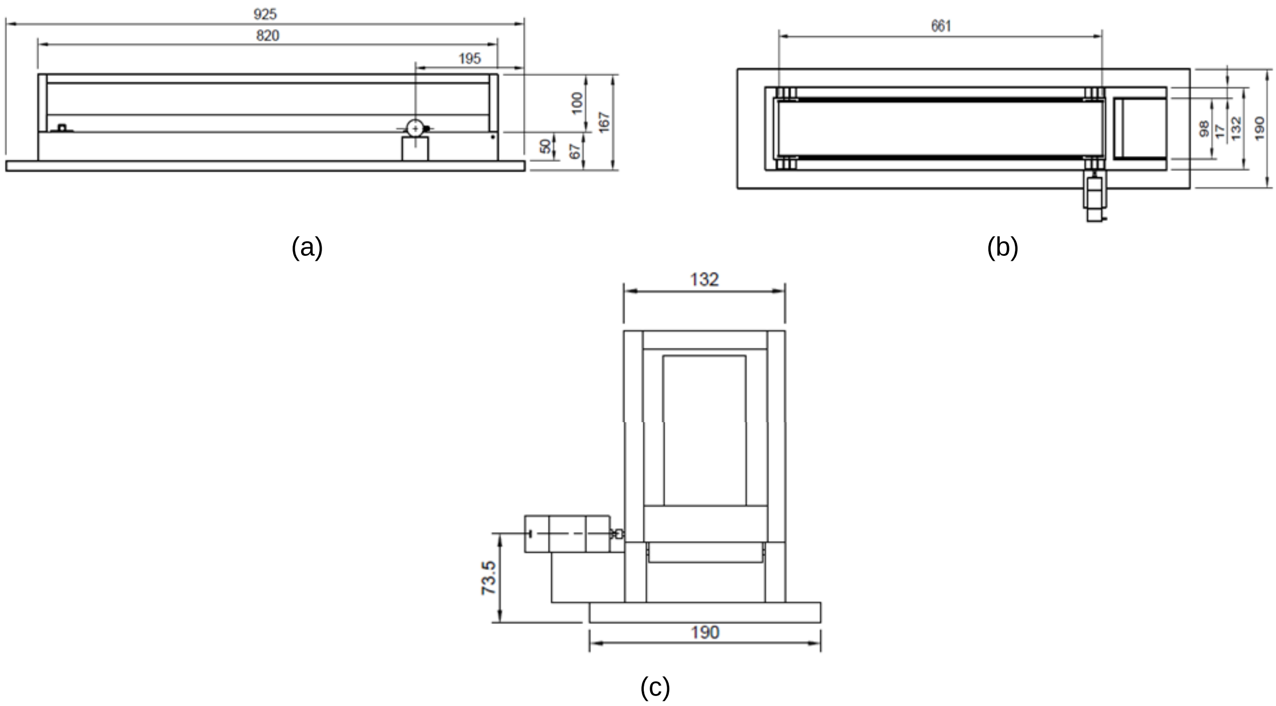

Figure 2. 2D sketch of a Trial Animal Treadmill (a) Left View, (b) Upper View, (c) Behind View

Table 1. Equipments

Name	Unit	Specifications	Justification
PC	1	AMD FX 8 Gb RAM	Design, programming, and retrieving test data
Fritzing Software	1	Fritzing 0.9.9	Design circuit diagram
Arduino IDE	1	Arduino.cc 2019	Arduino programming
MATLAB	1	R2019b	Data processing and test data visualization

Table 2. Consumables

Name	Unit	Specifications	Justification
Arduino Mega	1	Micro controler ATmega 2560	Main controller of the treadmill
Limit Switch	1	SPDT (*Single Pole Double Single*)	If the mouse is already in the tired area, (b)
Driver Motor	1	IC L298N	Adjusting and controlling the direction and rotational speed of the DC motor
LCD Module	1	20x4 I2C	Displaying information on a treadmill
Keypad	1	4x4 plastic membrane	Entering speed and other settings on the treadmill
USB cable	1	USB A 2.0 Male to USB B Male – 1 meter	Connecting cable between Arduino and rastic, and for power supply to system
Motor DC	1	DC 25GA370 12V 1000RPM	A Prime mover on the treadmill
SD card Module	1	VCC: 5V (4.5~5.5v)	Read and save data to SD card

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Speed *Encoder*	1	Magnetic Speed *encoder* Hall sensor	Sensors used to calculate the rotational speed of a DC motor
SD card Memory	1	4 Gb	Stores data of the treadmill
Jumper wire	1 set	2.54 mm Dupont Line 15 cm	Connective between every treadmill component

3.2 PID Control Design

PID (Proportional Integral Derivative Controller) control is a feedback mechanism controller that is often used in industrial control systems [22]. Figure 3 is a block diagram of PID control in a closed-loop DC motor system. As highlighted, it shows several processes in controlling the DC motor system that aims to stabilize the treadmill speed according to the setpoint [23]. Starting from giving the setpoint, then correcting the error between the setpoint and the DC motor speed when it is close to 0 (zero). Then, the PID controller controls the speed, produces PWM output, and becomes the DC motor input. The DC motor's output speed (RPM) will be read using the sensor and become feedback for error correction.

In the PID controller, there is a Transfer Function or Gc, which results from the sum of the values of Kp, Ki per constant duration, and Kd per constant duration [24]. Kp is a proportional gain that produces an output directly proportional to the error, Ki is an integral gain that will reduce or eliminate the error value, and Kd is a derivative gain that will be used to stabilize a system [25]. The application of PID control on DC motors by taking into account the specifications of the system as follows:

a. Rise time, is the duration of the system response rising from 10% to 90% of the final value of the specified system response.
b. Maximum overshoot (OS percentage), the maximum peak value of the system response curve measured from the final response.
c. Determination of the overshoot percentage value from Equation 1.

$$percentage\ (\%)OS = \frac{overshoot - setpoint}{setpoint} x100\% \tag{1}$$

4. Methodology

Several processes were observed in experimenting, as shown in Figure 4. This tool was experimented by giving experimental animals a load, such as albino rats or mice with a mass > 0 g, and had been given adaptation beforehand so they could follow the exercise well. The speed given is based on the individual ability of experimental animals who are given the training to observe their heart health. The given speed is increased to a maximum speed of 100 m/min or until the experimental animal is tired. Then, the PID controller controls the speed so that the DC motor will be active with the PWM value from the output of the PID controller. The speed of the DC motor will be recorded and read by the encoder sensor and stored on the SD Card in CSV (comma-separated value) file format.

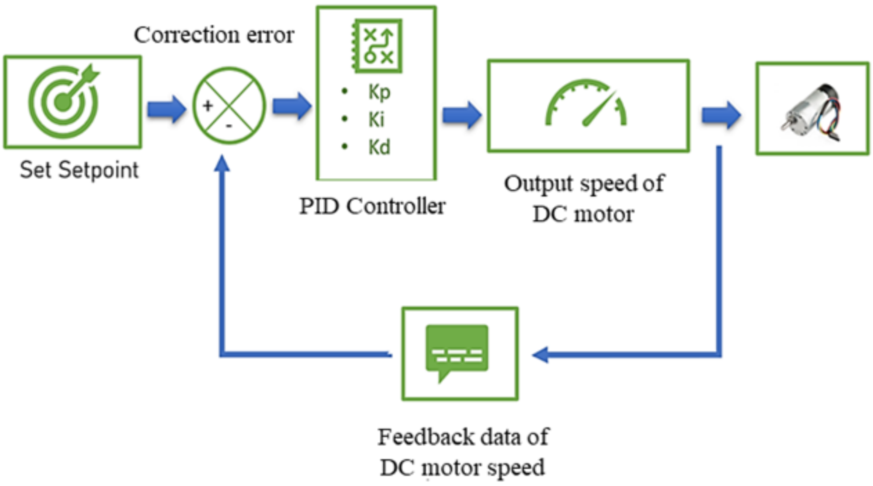

Figure 3. Block Diagram of Controlling a DC Motor System on a Treadmill

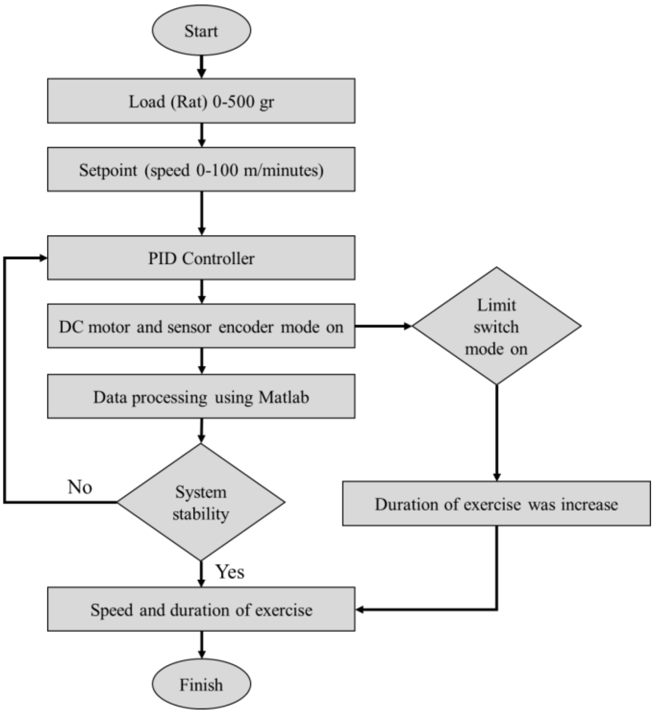

Figure 4. Flowchart of Experimental Animal Treadmill Working System

Furthermore, the data is processed using MATLAB software so that the system response produces overshoot and rise time values that determine the stability of the system. The steps that need to be done are reading the.csv file and determining the time, m/minute, and speed. The data is plotted and determine the legend. From these results, overshoot and rise time calculations can be made. In addition, if the experimental animal does not fall into the fatigue zone during exercise, then the exercise is continued, and the duration continues to increase. If the experimental animal gets tired due to falling into the fatigue zone, it will touch the limit switch sensor, and the exercise duration will stop. This device will display the final value of speed (m/min) and duration (minutes and seconds) of the exercise given to the object (test animal) on a 20x4 LCD, making it easier for users to observe the object's exercise ability.

5. Result and Discussion

The results of the design of the experimental animal (rat) treadmill, as shown in Figure 5 with the components listed in Table 2 and several other basic materials, then connected to a PC/laptop for programming and analyzing the data obtained using the software as shown in Table 1. Figure 5 shows that this tool has two rooms: the fatigue zone, a limit switch sensor, and a room for rat training. This is very useful for medical expert's research needs, especially cardiologists. The utilization of the tool can determine the speed and duration of exercise given to experimental animals. Then, this exercise dose can be used in humans to determine heart health based on the age of the experimental animals. To determine the quality of the PID control system, a comparison is made if the system does not use PID control. Figure 6 is the display of test results in experimental animals in the form of values of speed and duration of exercise.

Figure 5. Rat Treadmill Design Results

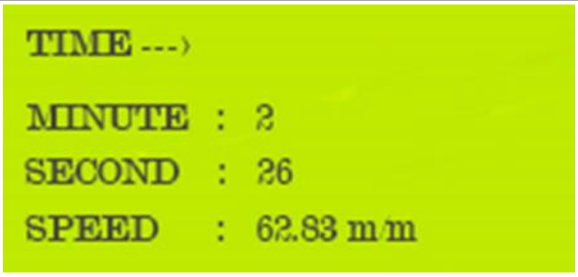

Figure 6. Speed and Duration Display on LCD

5.1 DC Motor Speed Control without Using PID Controller

Before testing the speed control of the treadmill using PID control, the speed test of the treadmill motor is carried out without using PID control as a comparison if PID control is used. This test works with the DC motor speed input that has been set without correcting the motor speed error. Error is a comparison of the current motor speed value with the set motor speed or setpoint. Based on Figure 7, it is found that controlling the speed of the DC motor without the use of PID control can cause the input speed of the DC motor not to reach the setpoint. This happens because there is no error correction that gives more input to reach the setpoint, so the condition can affect the training speed of the experimental animal because it does not match the desired speed or setpoint. Furthermore, system testing was carried out without using PID control which was given a load with an albino rat mass of 240 gr. Figure 8 is the result of testing system shows that if PID control is not used, the speed of the DC motor will not correct the error to reach the setpoint. These conditions can affect the provision of exercise to experimental animals because it does not followed the speed regulation. So, the DC motor requires more power to reach the setpoint. If compared between speed control tests without using PID control with load and without load, it shows the same response i.e., the speed of the DC motor does not reach the desired setpoint or speed. The test results of the speed control system without using PID with load resulted in a slower response and had a greater error compared to testing without load. This results in DC motors requiring more power than PID-less and no-load control systems. The graph results in the speed controller without PID there is a load and no load as in Fig. 7 and Fig. 8. A conveyor without load moving at a setpoint of 60 m/min, while with a conveyor load moving at a setpoint of 75 m/min.

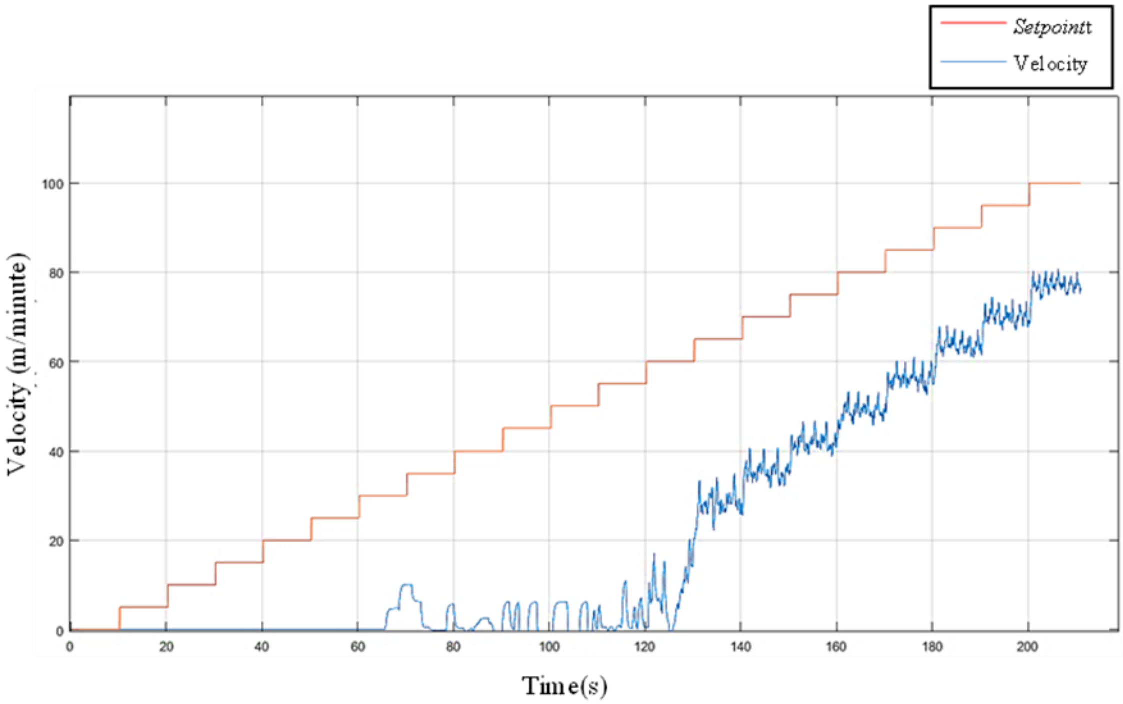

Figure 7. Graph of the Results of the Speed without PID Controller and without Load

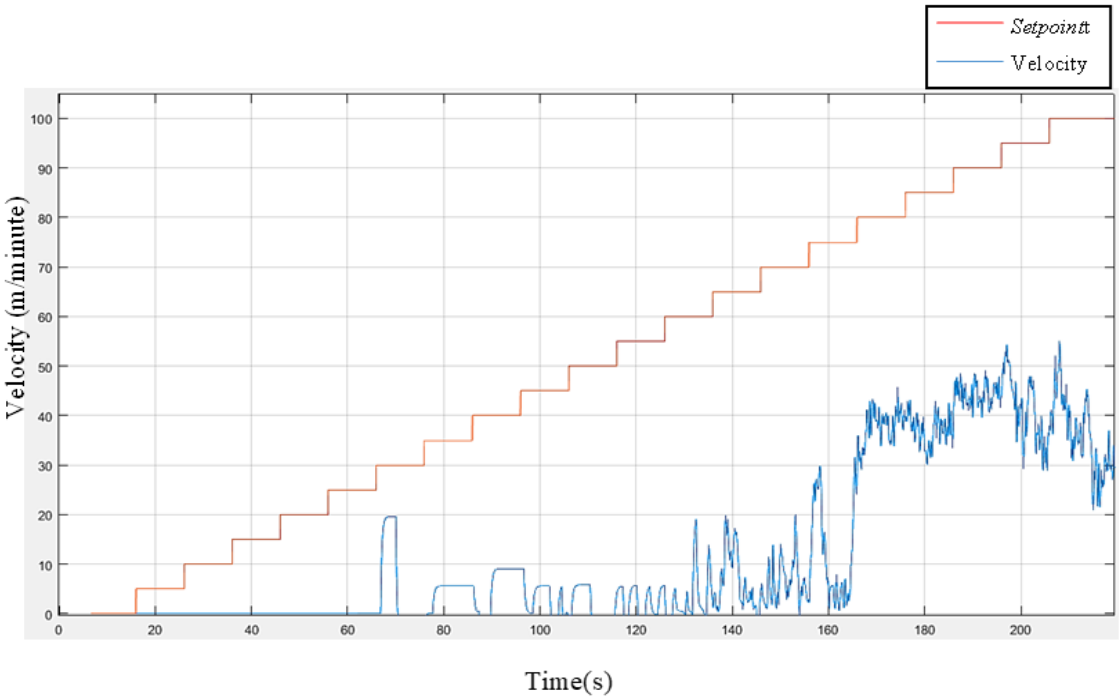

Figure 8. The Results of DC Motor Speed Control without PID Control with Load

If compared between speed control tests without using PID control with load and without load, it shows the same response i.e., the speed of the DC motor does not reach the desired setpoint or speed. the test results of the speed control system without using PID with load resulted in a slower response and had a greater error compared to testing without load. This results in DC motors requiring more power than PID-less and no-load control systems. The graph results in the speed controller without PID there is a load and no load as in Fig. 7 and Fig. 8. A conveyor without load moving at a setpoint of 60 m/min, while with a conveyor load moving at a setpoint of 75 m/min.

5.2 DC Motor Speed Control Using PID Controller

In this test, the constant values obtained from the trial-and-error method to produce a system that works well, namely Kp = 17, Ki = 7, and Kd = 1. The results of motor speed control tests with PID control can be seen from the motor speed system response graph in Figure 9 and Figure 10. Based on subsection 3 which states that the system response is good when the rise time and percentage (%) of overshoot produced is close to 0 (zero). Figure 9 is a graph of the results of speed control with no-load PID control. The results obtained were an average rise time and average overshoot in each setpoint test of 0.115 s and 6%, so it was stated that this test was successful. For instance, testing on a setpoint of 35 m / min with a rise time of 0.09 s and a percentage (%) overshoot of 6%. Then, testing the system using PID control given a load with an albino mouse mass of 240 gr.

Figure 10 is the result of controlling the speed of the treadmill with PID and with a load showing good system response and reaching the setpoint. At a duration of 45–55 s and a setpoint of 20 m/min there was a graph that dropped drastically because the rats refused to participate in the exercise due to not being given the adaptation or treatment to run on the treadmill beforehand, so the rats resisted the rotation of the belt. The system's response to the test results obtained an average rise time value of 0.14 s and an average overshoot percentage of 5%, so this test was declared successful. Furthermore, when compared with PID testing without load, it can be seen that the average value of rise time is greater. When there is no load by 0.115 s and when there is a load of 0.14 s, the average value of percentage (%) overshoot is lower, that is, when there is no load by 6% and when there is a load of 5%. This happens because of the load on the treadmill which results in the performance of the motor requiring more power to reach the setpoint and holding the motor to move more freely.

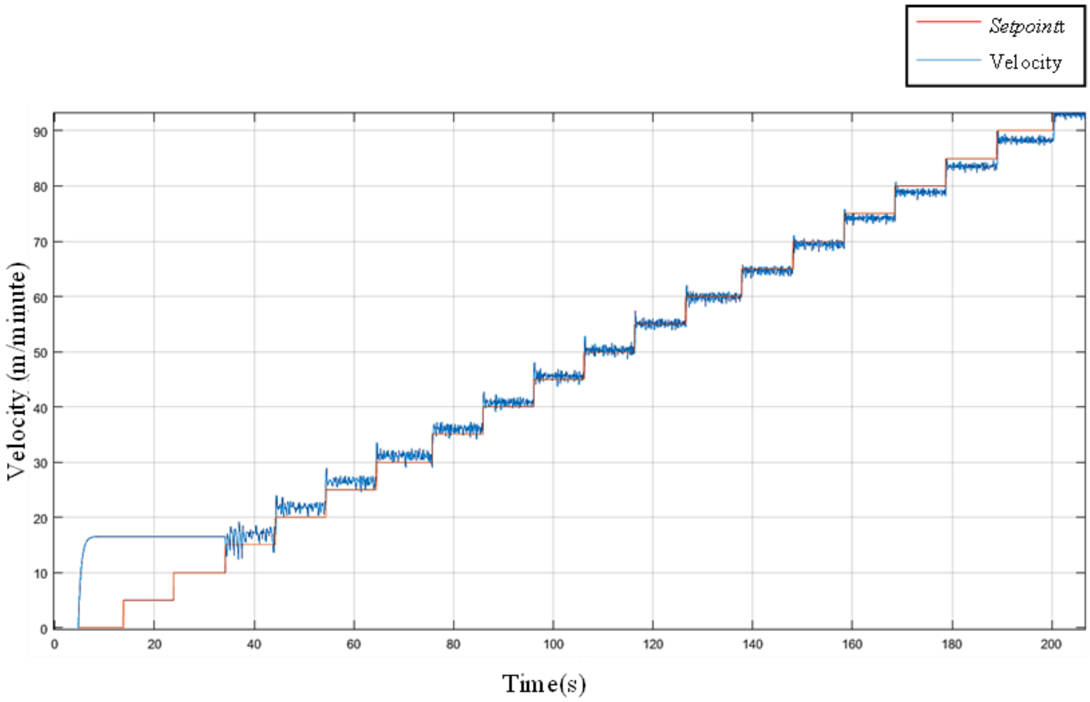

Figure 9. Graph of the Results of Speed Control with PID Controller and without Load

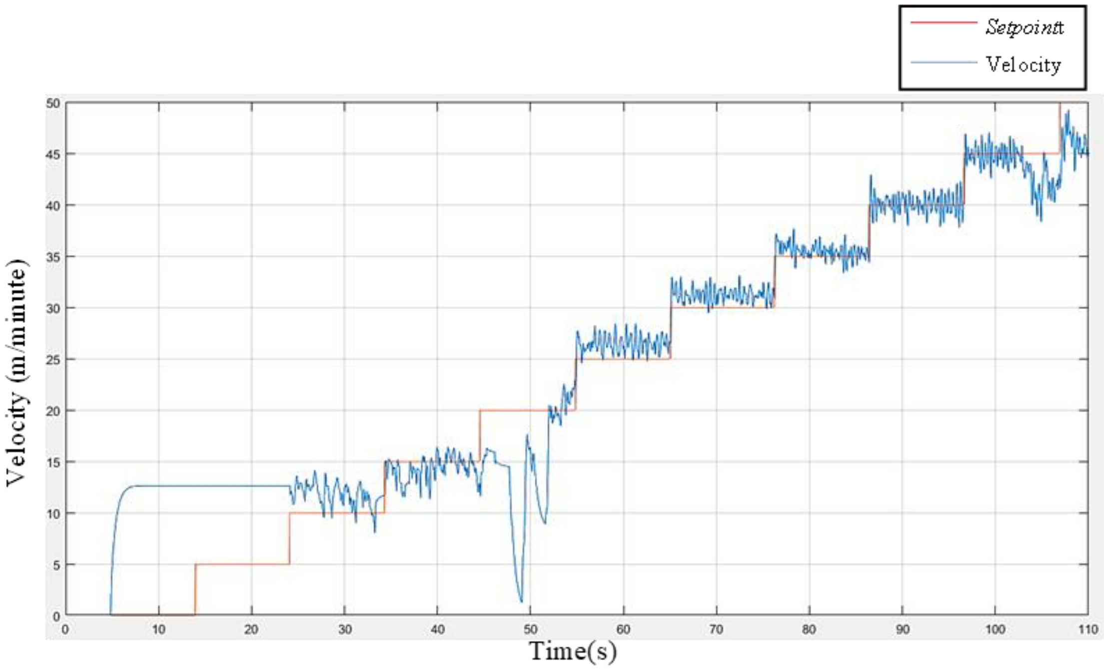

Figure 10. The Results of Controlling DC Motor Speed using PID Controller with Load

5.3 Evaluation of Tool Systems with PID Control

The treadmill speed control system was evaluated on several experimental animals with different body weights (as shown in Table 3). The instrument testing was carried out for 5 minutes for each object. Setpoint repeated for each object 0-100 m/min and given a rest on the DC motor after 40 minutes of work or when the tool is hot to maintain the durability of the tool. Based on Table 3, the optimum speed is different for each mass of load because the experimental animals used are dynamic loads that move every time, which causes the belt on the treadmill to experience different pressures every time. The optimum speed value is not always directly proportional to the mass of the load. The average value of the percentage (%) of overshoot obtained is 10%, and the average value of rising time is < 1 second. The system that uses PID control produces a good system response, and the percentage value of the system accuracy is

90% start from a setpoint of 35 m/min as shown in Fig. 10. Thus, it can be concluded that the experimental animal treadmill that controls speed using PID control with the constants Kp = 17, Ki = 7, and Kd = 1 is declared successful. In this study, we apply encoder sensors and limit switch sensors as a reference for the dose of exercise that will be given to patients in the form of speed and duration of exercise.

Table 3. Treadmill Speed Control System Evaluation Results

Name	Age (month)	Massa (gr)	Velocity (m/min)	Overshoot (%)	Rise time (s)
Rat	4	224	25	2	0.1
	4	211	15	7	0.31
	4	230	15	7	0.49
Mus	2	28	35	7	0.12
	2	30	20	10	0.04
	2	27	20	6	0.08
	2	24	30	10	0.08

The tool designed in this study is the development of a tool that is not owned by previous research [2]. This study successfully designed a treadmill that has an automatic system in determining the speed and duration of exercise. Therefore, the existence of this system facilitates testing conducted by researchers on rats. When compared to previous research [11] which designed a mini conveyor with the use of PID control in controlling DC motors, the determination of PID constants greatly affects the results of DC motor performance and encoder sensor measurements. As well as in this study which tested the device without load, it is able to get the best constant value to produce a good system response. The system response values obtained in this study are competitive because they are tested on moving objects, so the overshoot and rise time values of the constants determined depend on the load used. Therefore, this study was successfully designed by utilizing PID control and the device can be used with various masses of rat loads.

6. Conclusion

This research has been successfully carried out, namely testing the PID controller as an experimental animal treadmill controller, speed control without PID control results in a disturbed DC motor speed and does not reach the setpoint. Speed control on a special treadmill for experimental animals using an encoder sensor that can read the speed well and the utilization of PID control with a constant that can control the speed so that the tool can work stably. Speed control using PID control can control the speed of the treadmill with stability and good system response, as shown in Fig. 8. The results of the system response controlled with constants Kp = 17, Ki = 7, and Kd = 1 obtained a percentage value (%) overshoot of 5%, and a rise time value of 0.14 seconds. System performance with a percentage of 90% accuracy, so this research is achieved and declared competitive. However, due to the construction that is not smooth so that the overshoot obtained is high even though it is still within the tolerable error limit. Further research is suggested to develop better construction so that it can determine a better PID constant value for controlling the speed of the tool and can be developed so that it does not require a PC/laptop connection in controlling the system or controlled wirelessly and adding an automatic button to start and stop the exercise.

Acknowledgement

Thank you to the Grant of Lektor from LPPM, Universitas Syiah Kuala, which has supported this study. Hopefully, this study can make a major contribution to the advancement of technology in Indonesia.

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