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Real Time Comparison between PID and Fuzzy Logic Controller for DC Motor Speed Control

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Abstract

The diversity in DC motor application in robotic, heavy manufacturing and transportation have caused the usage of the controller in speed control mechanism become a main priority. PID controller is a common controller used in the industry due to its esy and straightforward design. However, the PID controller face challenges when the plant model contains the nonlinear characteristics. To overcome this situation, Fuzzy Logic controller is used as the controller as it can make decision based on the uncertain and vague inputs. In this study, the PID and Fuzzy Logic is applied and analyzed to decide the controller with better output response. The overshoot, undershoot, transient time and settling time are the indicator used to compare the controller output response. The hardware DC model is integrated with the Simulink DC motor model by STM32F411RE microcontroller. System identification is used to determine the plant model transfer function for the PID controller design process. The Fuzzy Logic controller is designed in MATLAB Fuzzy Logic Toolbox. 25 fuzzy rules are derived from five memberships function that are applied in the Fuzzy Logic controller design for the inputs and output. The result implies that Fuzzy Logic controller have a better response than the PID controller. This is shown by the lower overshoot of 0.7746% compared to PID overshoot of 3.4619%. The time taken for transient and settling time is shorter by using Fuzzy Logic controller by 1.1805s compared to PID controller transient and settling time of 1.2236. The output response waveform of both controllers are being observed and compared in this paper.

1. Introduction

DC motors were extensively adopted because direct-current power distribution networks can supply the electrical energy to them. DC motor speed can be affected by modifying the supply voltage or the magnitude of current in its field windings. The electric vehicles, lifts and hoists, and steel rolling mill drives are the example of DC motor application in heavy industry (Schagin Anatolii et al., 2017). To achieve accurate and precise speed control, a number of control techniques may be used in DC motor speed control.

The DC motor speed and position control could become possible due to implementation of Proportional-Integral-Derivative (PID) controller. Because of its plainness and straightforward design, cost-effectiveness, and

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wide variety of applications, proportional-integral-derivative (PID) controller is the most common controller being utilized to monitor and conduct the industrial processes (Hussein & Abdullah, 2020). PID controller must contain three components: a proportional gain (kp), an integral gain (ki), and a derivative gain (kd), to provide the optimum feedback response from system. The benefits of utilising a PID controller for DC motor speed control include its ability to respond quickly and accurately to changes in the system, its ease of installation, and its capacity to manage varied process dynamics and disturbances. PID controllers are also commonly utilised due to its versatility to many types of systems and simplicity of tweaking for maximum performance. However, PID controllers have limits (Ahmed et al., 2017). PID controllers, for example, may struggle to manage nonlinearities in the system or retain stability in the midst of massive shocks. Its ability to reduce the deviation between setpoint input and process output in short period is one of the challenges PID controller have to deal with (C. Sánchez–López et al., 2019). The nonlinear characteristics of DC motor can cause performance of PID controller to be degraded.

To overcome this problem, the fuzzy logic controller is introduced. The idea of fuzzy sets was developed by Prof. Lofti Zadeh in 1965. Set theory contributes a vital role for recognising membership function or degree of membership that can help the controller to made decision with vague and uncertain information (Shashank Pareek et al., 2023). The fuzzification, rule base, inference and defuzzification are the important component that is required in designing the fuzzy logic controller. The advantage of using a Fuzzy Logic controller is its ability to effectively handle nonlinearities and uncertainties in the system, making it a robust option for DC motor speed control. By using linguistic variables and fuzzy rules, a Fuzzy Logic controller can provide precise and robust control, overcoming some of the limitations of PID controllers in certain scenarios.

In this work, the PID controller and Fuzzy Logic controller is implemented into the system by using the appropriate technique for the design of controller. The overshoot, undershoot, settling time and its transient time of the controller will be compared to each other. The work consists of software part, which include the design of the controllers in MATLAB Simulink and hardware part, which included the DC motor with the encoder. STM 32 F411RE microcontroller is used as the interface between the control system controller and the DC motor hardware model.

2. Materials and Method

2.1 System Identification

The System Identification Toolbox in MATLAB is a useful tool for simulating and studying dynamic systems. It may be used by engineers and scientists to estimate linear and nonlinear models based on input-output data. The toolbox includes a variety of techniques for model estimates and validation, as well as support for diverse models such as transfer functions, state-space models, and non-parametric models (Tang et al., 2017). The System Identification Toolbox is used to determine the parameters of a DC motor transfer function using experimental data in the specific instance of a DC motor transfer function. This is critical for understanding DC motor behavior and building control systems that successfully manage its speed or position (MATLAB, 2017a). Fig. 1 shows the MATLAB command window 'systemIdentification' to open the toolbox. The toolbox graphical user interface will appear as exhibits in Fig. 2. Fig. 3 shows the Simulink open-loop DC motor model.

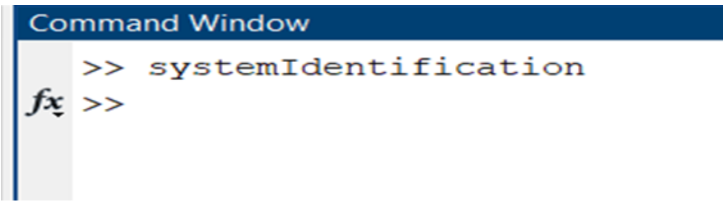


Fig. 1 *MATLAB command window 'systemIdentification'*

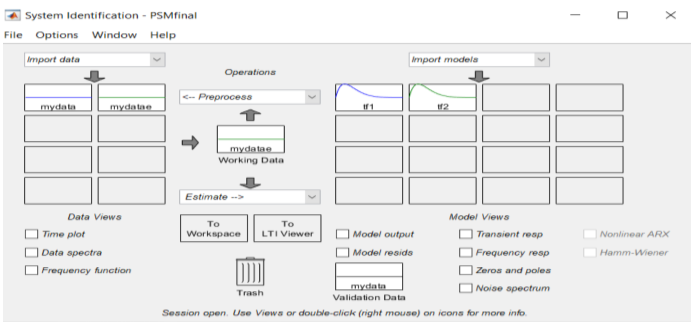


Fig. 2 *System Identification Graphical User Interface*

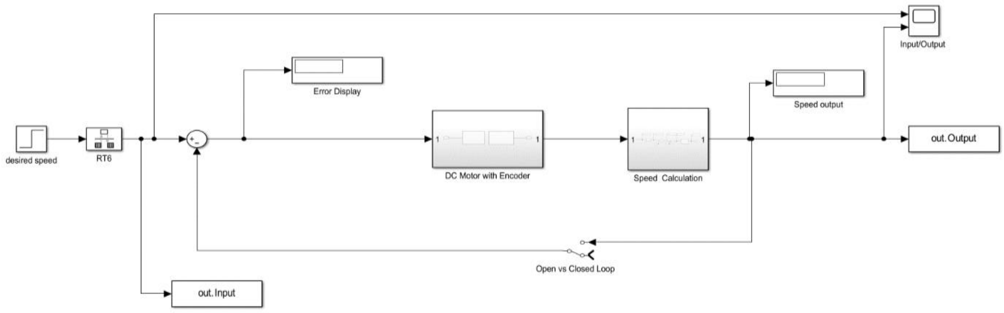


Fig. 3 *Simulink DC model open loop system*

Model estimation methods such as time-domain and frequency-domain methods are included in the toolbox, as are strategies for model validation and model selection, as well as tools for assessing the accuracy and dependability of the identified models.

2.2 PID Controller Design

PID control, one of the most widely used controllers, may be used to establish and maintain the process set point. Although the applications of PID control differ, the methodology is the same. To compute the values of the parameters Kp, Ti and Td, the Ziegler-Nichols First Method Tuning Rule is employed (Devendra Somwanshi et al., 2019). To determine the error value between the measured output data and the intended set point, the Ziegler - Nichols tuning method is utilized. The effect of the parameter increase is summarized in Table 1.

Table 1 *Effect of increasing parameters*

Parameter	Rise time	Overshoot	Settling Time
K_p	Decrease	Increase	Small Change
K_i	Decrease	Increase	Increase
K_d	Small Changes	Decrease	Decrease

Table 2 *Ziegler-Nichols Tuning Rule First Method*

	K_p	T_i	T_d
P	$\frac{T}{KL}$	-	-
PI	$\frac{0.9\,T}{KL}$	$3.3\,L$	-
PID	$1.20\frac{T}{KL}$	$2.2L$	$0.5L$

The Ziegler-Nichols First technique tuning technique formula is shown in Table 2 for calculating the parameters Kp, Ti and Td. We may utilize the first approach of Ziegler-Nichols Tuning Rule since the step response of the DC motor model can be identified using the System Identification Toolbox in MATLAB. The delay time, L, time constant, T, and steady state value, K are the significant parameters utilized in the Ziegler-Nichols First procedure tuning procedure (Parikh et al., 2018). The value of the profits will only be utilized dependent on the kind of controller chosen.

2.3 Fuzzy Logic Controller Design

The inputs "Error" and "Change Error" are used in this research. To enhance the signal, the system is under close loop feedback control, which means that two inputs must be used to generate one output (Younis, 2018). The membership functions for "Error" and "Change Error" are -6 to 6 and have five inputs: Negative Big (-B), Negative Small (-S), Zero (0), Positive Small (+S), and Positive Big (+B). The fuzzy logic controller's rules are written in the "If Then" language. The If side represents the mistake's condition, while the Then side represents the conclusion. As shown in Table 3, there are 25 rules for monitoring the output value of a DC motor. The 25 rule is composed of five input errors (E): Negative Big (-B), Negative Small (-S), Zero (Z), Positive Small (+S), and Positive Big (+B), as well as five input "Change Error" (DE): Negative Bithe input membership function of “Error” and “Change Error” that are being used in this research.

Table 3 *5x5 fuzzy rule for Fuzzy Logic controller*

Error \ Change Error	Negative Big (-B)	Negative Small (-S)	Zero (Z)	Positive Small (+S)	Positive Big (+B)
Negative Big (-B)	-B	-B	-B	-S	Z
Negative Small (-S)	-B	-B	-S	Z	+S
Zero (Z)	-B	-S	Z	+S	+B
Positive Small (+S)	-S	Z	+S	+B	+B
Positive Big (+B)	Z	+S	+B	+B	+B

The “Error” and “Change Error” input is ranged from -6 to 6 and have five membership function which are Negative Big (-B), Negative Small (-S), Zero (0), Positive Small (+S) and Positive Big (+B).

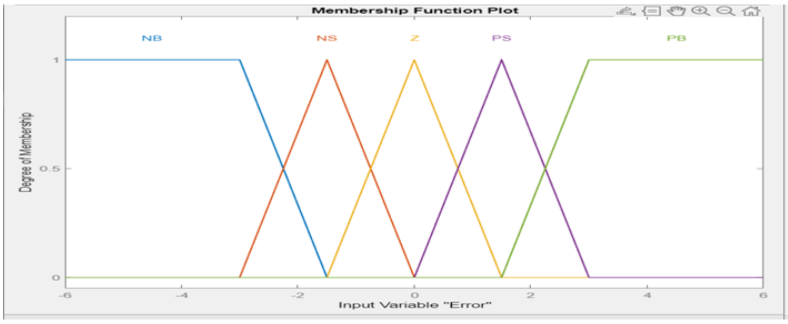


Fig. 4 *Membership function of “Error” input*

The defuzzification process in this work is based on the Mamdani type, which may define the fuzzy set for both input and output parameters. The output extends from -255 to 255 and has five separate outputs, as shown in Fig. 5.

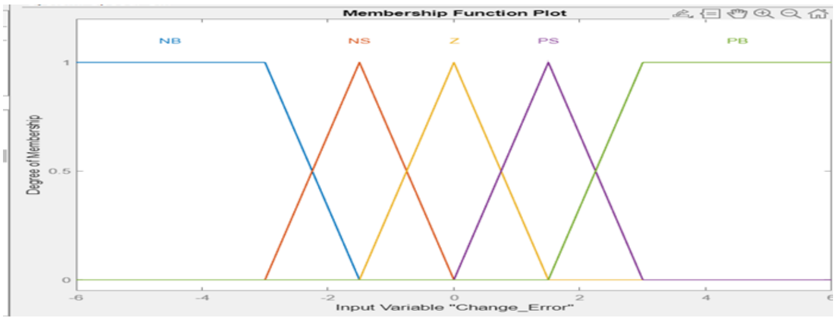


Fig. 5 *Membership function of “Change Error” input*

Negative Big (-B), Negative Small (-S), Zero (Z), Positive Small (+S), and Positive Big (+B). Fig. 6 shows the membership function of output.

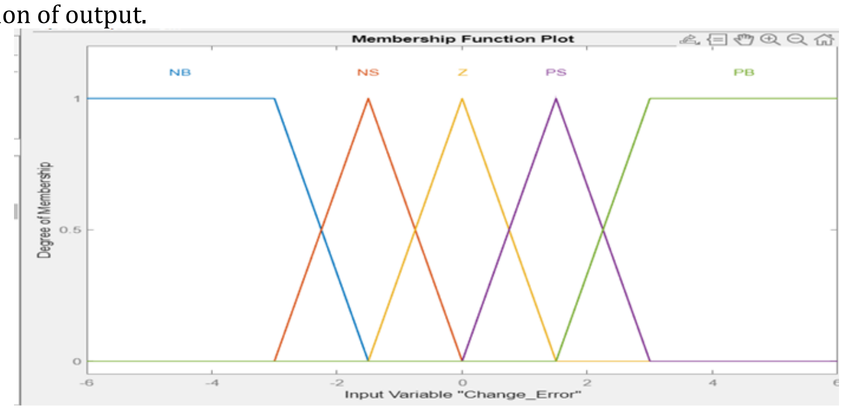


Fig. 6 *Membership function of “Output” output*

2.4 Hardware Model

Fig. 7 shown the real time hardware configuration for the work. The STM32 microcontroller board will act as the interface between the controller and the hardware. A DC motor with an encoder, a motor driver, and an STM32 controller comprise the control system. The conveyer belt connects the direct current motor to the encoder and gives feedback, allowing the output speed to be changed to meet the needed speed. The DC motor is linked to the STM32 F411RE microcontroller, which generates a PWM signal. For the speed calculation function, the microcontroller will write the digital signal from the PWM output to the encoder. Encoders are devices used in DC motor speed control to measure the speed and position of the DC motor by providing feedback to the controller. The encoder is connected to the STM32 F411RE microcontroller, which delivers the encoded digital signal to the laptop.

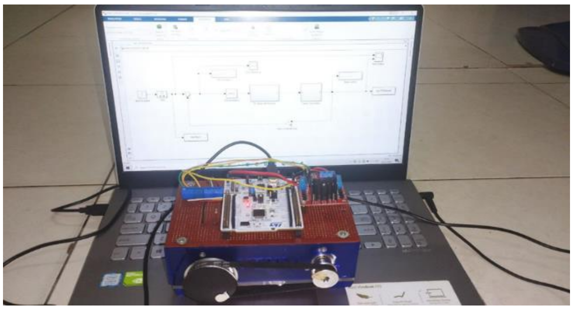
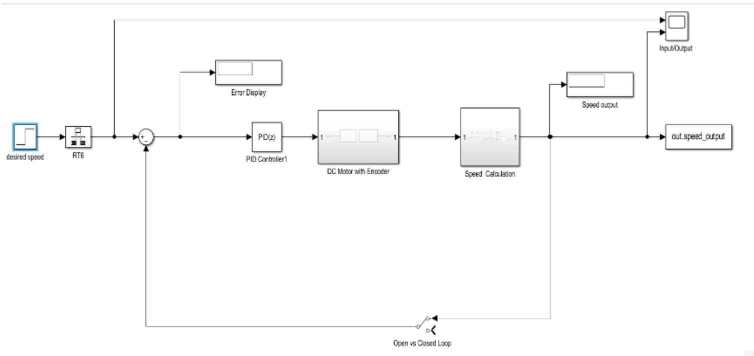
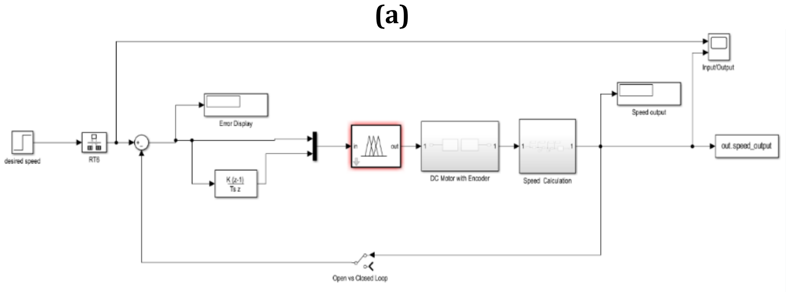


Fig. 7 *Real hardware configuration*



(a)



(b)

Fig. 8 *a) PID controller used in Simulink model. b) Fuzzy Logic controller used in Simulink model*

The MATLAB Simulink model system with PID and Fuzzy Logic controller implementation is shown in Fig. 8. Because the simulation is performed in a closed loop system, the available system controllers are PID and Fuzzy Logic. The input is a step source block with a fixed point of 150 rpm.

3. Result and Discussion

The transfer function of the DC motor is determined using the system identification technique in this work. In order to determine the best fit transfer function model between estimated and tested data, a collection of data from the open-loop DC motor control system's input and output is gathered for DC motor model estimation. According to the simulation data, the estimated model has a best fit of 95.69%, which is acceptable the mathematical model for a DC motor can be derived from the result as shown in Fig. 9.

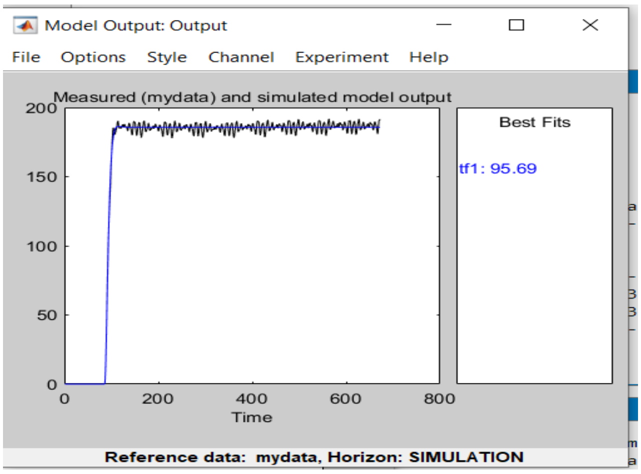


Fig. 9 *Model output of the system*

Transient response is a fundamental concept in control system theory. It plays a significant role in designing the controller for DC motor systems since it gives vital information for the system's performance. Fig. 10 shows DC motor model transient response.

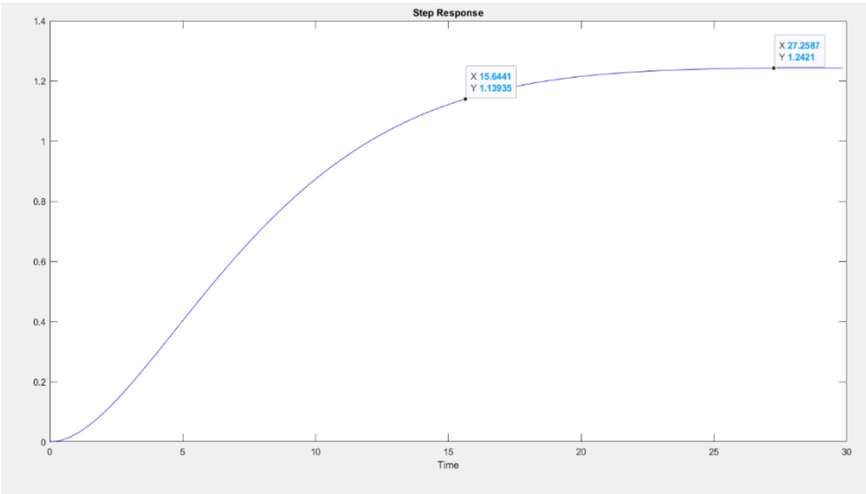


Fig. 10 *Transient Response of the system*

Table 4 shows the computed result using the Ziegler-Nichols First approach, where K is 1.24, L is 0.2370, and T is 15.6441. Only PID values will be utilized in this experiment since it compares PID and Fuzzy Logic controllers.

Table 4 *Ziegler-Nichols Tuning Rule First Method*

	K_p	T_i	T_d
P	53.2293	-	-
PI	47.9064	0.7821	-
PID	63.8752	0.474	0.1185

The input speed for DC motor is 150 RPM and it is run for 20 seconds. At first, the PID controller algorithm will be send to STM32 F411RE microcontroller that act as interface between DC motor and personal laptop. The result of the PID controller is shown in Fig. 12. The purple line is the input speed, and the blue line is the output for the speed of the DC motor using PID controller. Based on the result obtained in Fig. 11, the overshot of the controller is 3.4619%, rise time is evaluated at 0.0456s and the settling time is 1.2236s at set point of 150 rpm.

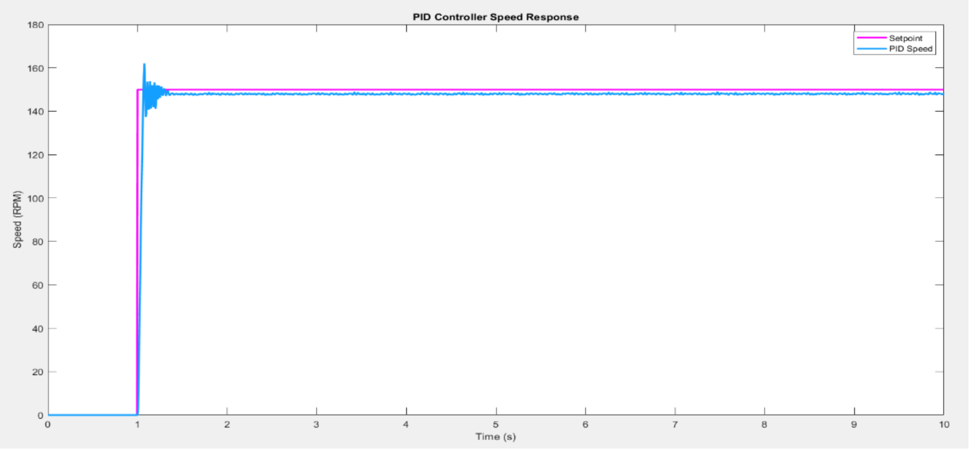


Fig. 11 *PID controller output response*

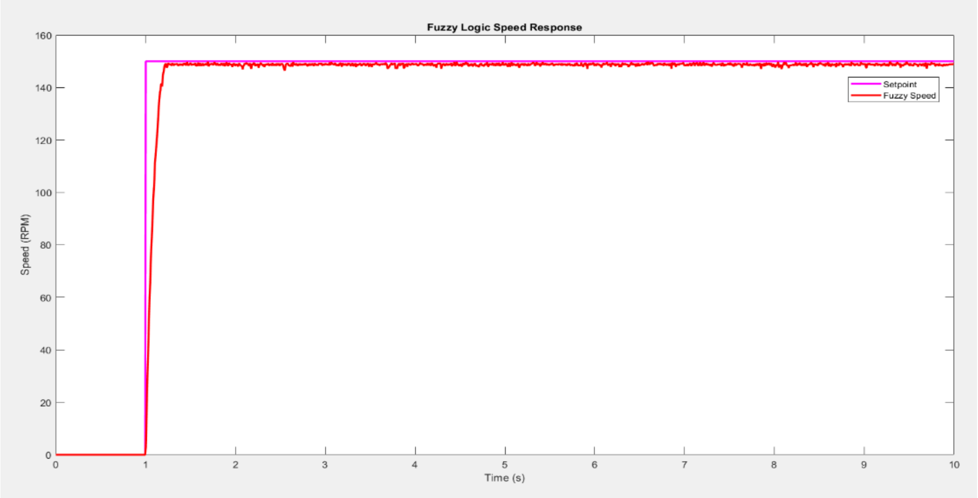


Fig. 12 *Fuzzy Logic output response*

The second experiment is executed by using Fuzzy Logic Controller. The result of the Fuzzy Logic controller is shown in Figure 13. The purple line is the input speed and the red line is the output for the speed of the DC motor using Fuzzy Logic controller. Based on the result obtained in Fig. 12, the overshoot of the controller is 0.7746%, the rise time is recorded at 0.1374s and the settling time is 1.1805s at set point of 150 rpm.

Table 5 *Comparison between PID and Fuzzy Logic controllers findings*

Parameters	PID	Fuzzy Logic
Overshoot (%)	3.4619	0.7746
Undershoot (%)	3.825	0.505
Transient Time (s)	1.2236	1.1805
Settling Time (s)	1.2236	1.1895

Table 5 summarizes the findings for PID and Fuzzy Logic controllers. According to a comparison of controller behavior, Fuzzy Logic controller is the best controller for this transfer function mod. In other words, it has the least amount of overrun while maintaining the appropriate speed. Furthermore, it responds quickly to reach the steady state error. Fig. 13 shows the output response waveform comparison between PID and Fuzzy Logic controller.

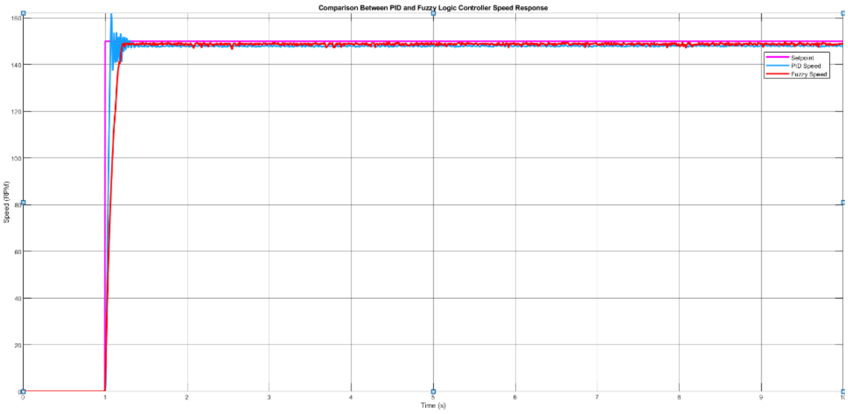


Fig. 13 *PID and Fuzzy Logic controller output response comparison*

4. Conclusion

Speed control of DC motor hardware model comparison is successfully executed with implementation of PID and Fuzzy Logic controller into the DC motor control system. The hardware DC motor model is integrated with the MATLAB Simulink model in the computer by using the STM32 F411RE microcontroller. System Identification is used in the PID controller design by identifying its transient response waveform to identify the time delay, L, time constant, T and steady-state constant, K. Five membership function is used for each inputs and output with implementation of 25 fuzzy rule for DC motor speed control with Fuzzy Logic Controller. The result obtained from the experiment indicates Fuzzy Logic controller have a better output response than PID controller by achieving smaller overshoot, undershoot, transient time and settling time. At the input speed of 150 rpm, the output response of Fuzzy Logic controller is 0.7746% compare to PID'S 3.4619%. The Fuzzy Logic have a better response by achieving a transient time and settling time of 1.2236s compared to PID's 1.11805s which is higher than Fuzzy Logic Controller. Based on the result, it can be concluded that Fuzzy Logic can be used in DC motor speed control as it can provide high efficiency, accuracy and performance when the DC motor system needed the controller with high performance. The PID controller can achieve stability in its performance by tuning the PID gains based on appropriate system identification technique to identify the suitable DC motor transfer function model.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors attest to having sole responsibility for the following: planning and designing the study, data collection, analysis and interpretation of the outcomes, and paper writing.

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