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DC Motor Speed Control and Evaluation using PID Controller

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Abstract

The direct current (DC) motor is a crucial drive configuration used in a variety of applications, accommodating a wide range of power and speeds. Due to its adaptable characteristics, it is extensively applied in variable-speed drives. This project aims to regulate and evaluate the speed of a DC motor, a task of great importance in industrial settings where precise control and stability are essential for optimal performance. However, achieving precise speed control in DC motors while minimizing energy consumption and maintaining cost-effectiveness remains a significant challenge. The goal of this project is to develop PID controllers that can ensure efficient and accurate speed regulation of DC motors across various applications, including robotics, automation, and renewable energy systems. Specifically, this project will evaluate the speed control of a DC motor using a PID controller implemented in MATLAB-SIMULINK. The DC motor will be interfaced with MATLAB-SIMULINK through an Arduino Uno board, which serves as a low-cost data acquisition device. A Graphic User Interface (GUI) for the PID controller will be created in MATLAB to set the desired motor speed, which will then be transmitted to the DC motor via the Arduino Uno board and data will be obtained at 0.1ms sampling time. With the successful completion of this project simulation studies proved the effectiveness of PID controllers designed.

1. Introduction

The direct current (DC) motor means electrical energy converts to mechanical energy and is always used in industries. The application of speed controllers used on a large scale, easy and used in many ways. In most applications, speed and direction are especially important. The purpose of a motor speed controller is to take a signal representing the demanded speed and to drive a motor at that speed [1]. DC Motor plays a crucial role in research, industry and laboratory experiments because of their simplicity and low cost [2]. The speed of the motor can be controlled by three methods namely terminal voltage control, armature rheostat control method and flux control method. A control system is an interconnection of components forming a system configuration that will provide a desired system response [3]. The separately excited DC motor is a high-performance variable speed drive vital for industrial applications such as robotics, actuation, control and guided manipulation because of its precision, simplicity, continuous control feature and wide speed range. Hence there is a need to accurately regulate and drive the motor at desired speed [4]. The main objective of DC motor speed control is to produce the desired speed within a certain reference value range in the shortest time and to reject environmental disturbances such as load alterations and changes in operating conditions [6].The proportional-integral-derivative (PID) controller was first proposed in 1922 by Minorsky1 and first applied for industrial applications in 1932. The PID controller has been playing the most significant role as the heart of control engineering practice in the feedback control system due to ease of use and simple realization [7], [8]. The PID controller serves as a standard feedback loop element in industrial control applications. It functions by comparing the gathered data with a reference value, and subsequently computes a new input value based on this disparity. The goal is to enable the system data to either approach or maintain the reference value [9]. In the speed control of a DC motor, Proportional, Integral, and Derivative (PID) controllers are often employed to guarantee efficient operational performance. Figuring out the PID coefficients for a DC motor, applicable in any system, requires knowledge of the motor's technical specifications [10]. Currently there are many methods in PID design including Ziegler Nichols formulae, back calculation and autotuning. Therefore, this study focusses on comparative studies of PID with zn tunning, Pid with back calculation and zpid with autotuning towards providing better regulation of speed dc motor.

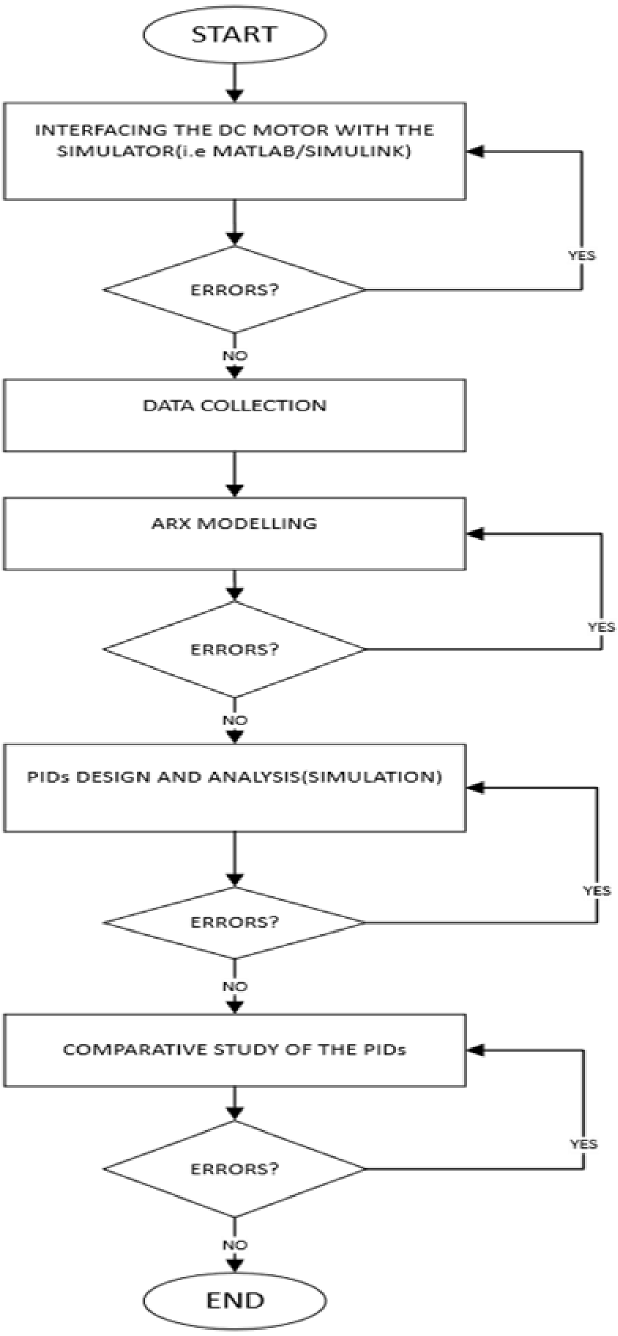

Fig. 1 *The flowchart of the study*

2. Methodology

Fig. 1 shows the sequences of tasks required to conduct this study. It begins by explaining how the hardware and software components are connected, which is essential for setting up data acquisition using an Arduino Uno board. Next, the data collection phase, where motor speed data is gathered and processed. This data is crucial for developing the ARX (Auto Regressive with external input) model, which helps to understand and predict the motor's behavior. The insights gained from the ARX model are then used to design and tune the PID (Proportional-Integral-Derivative) controller. The PID design phase focuses on creating a controller that can precisely regulate the motor's speed by adjusting its input parameters. Finally, the real-time testing phase involves applying the PID controller in practical conditions to ensure it performs as expected and meets the required specifications. This structured approach provides a comprehensive understanding of the project's progression and the integration of its various components to achieve effective DC motor speed control in Fig. 1.

2.1 System interfacing

Fig. 2 shows the system interfacing of this study. The open loop model designed using SIMULINK, which contains four units, the data acquisition unit which reads the pulses from the dc motor encoder, the rpm conversion unit which contains the mathematical expression to convert encoder's pulses to rpm, the visualization unit for monitoring the speed and sampled pulses as well as revs and finally the speed control unit for the regulation of the DC motor's speed, all connected and interfaced with hardware setup for the purpose of data collection. Fig. 3 and Fig. 4 shows the hardware connection diagram and the experimental setup of the interfacing.

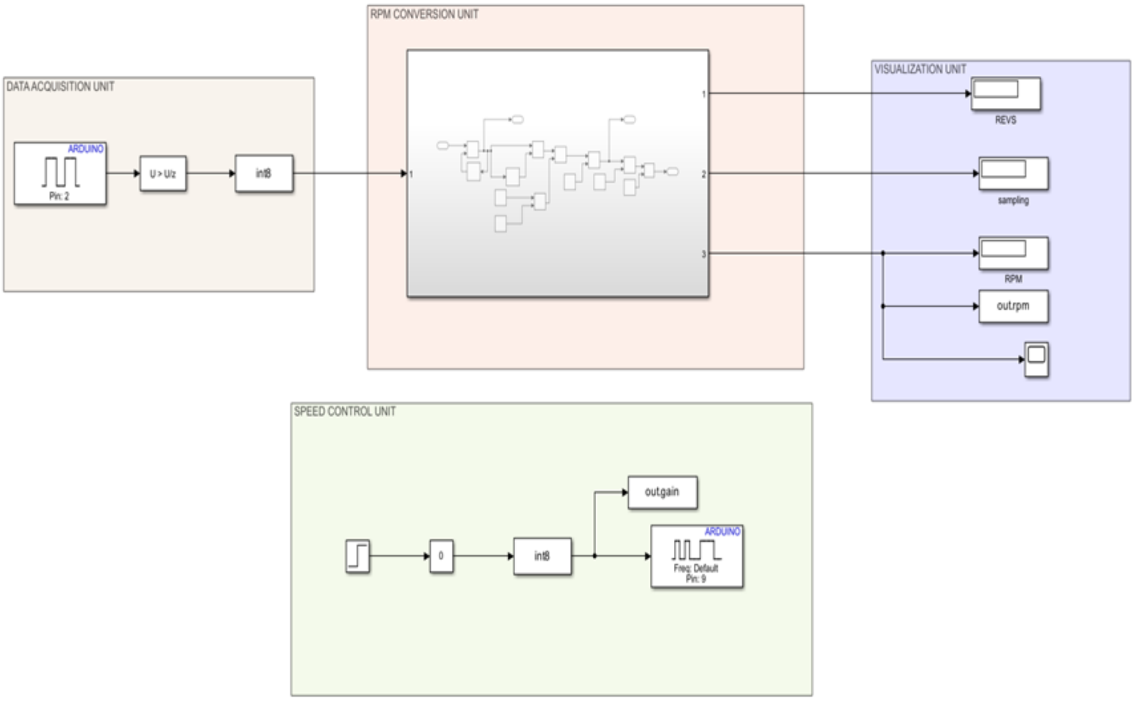

Fig. 2 *Open loop model*

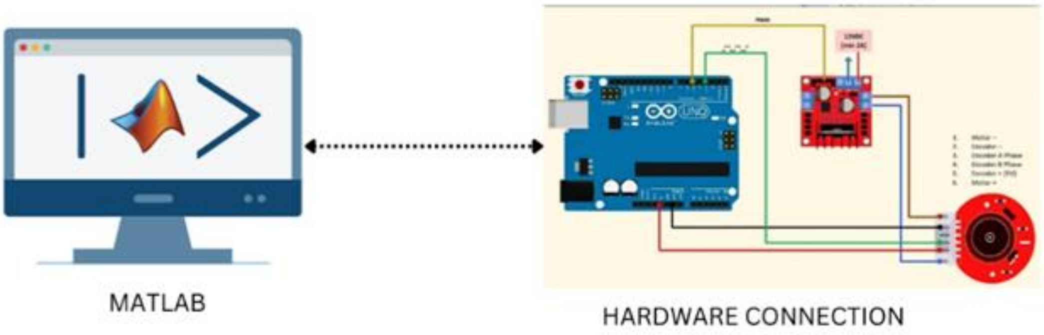

Fig. 3 *Hardware connection diagram*

Fig. 4 *Experimental setup*

2.2 ARX modelling

Fig. 5 and Fig. 6 show the ARX modelling analysis and the best fits interface from the analysis, used on the acquired data to obtain transfer function for the PID design and simulation.

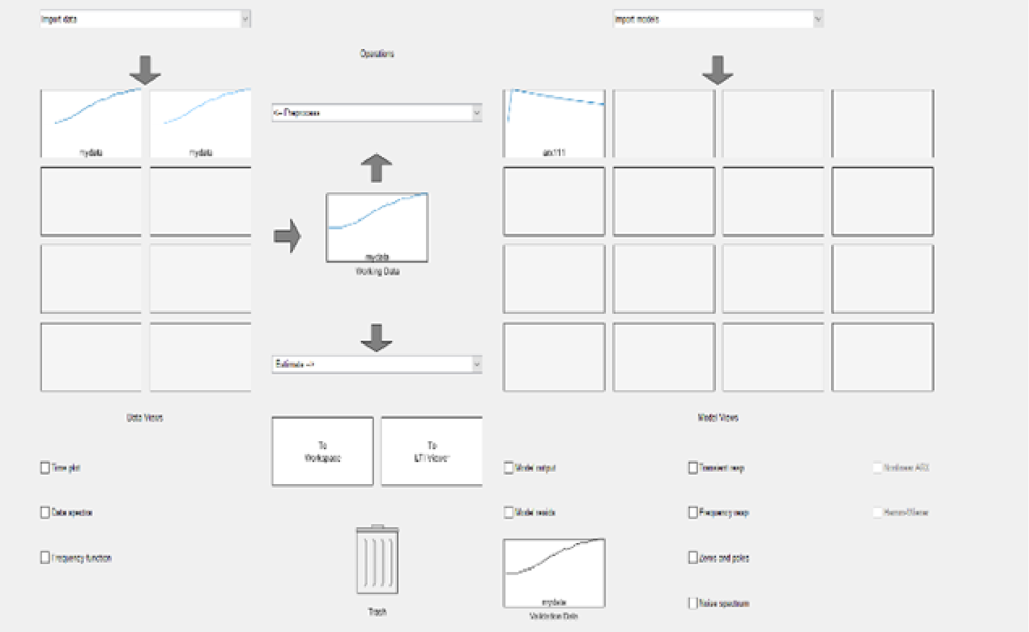

Fig. 5 *ARX modelling analysis*

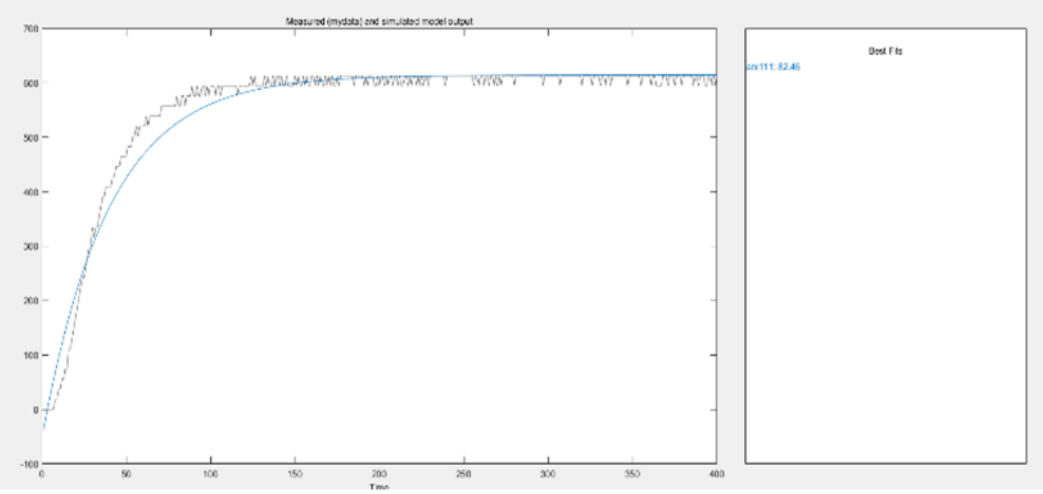

Fig. 6 *Best fits interface*

2.3 PID design

The design of PID practically for the Ziegler Nichol's PID will be based on input and output open loop data. Based on the input and output of the open loop data, the process parameters which are process gain, time constant and time delay were obtained using Process Reaction Curve, PRC, based on these parameters, the PID parameters are calculated based on the Ziegler Nichol's formulae as shown in Table 1.

$$Ta = \sqrt{Ti.Td} \tag{1}$$

Meanwhile, for PID with back calculation with anti-windup, the value of time tracking constant Ta is calculated with the formula in Equation (1). Based on the derived data and the step response obtained from the open loop model, the labelled parameters k, θ and τ were calculated using process reaction curve (PRC) method and Ziegler Nichol's PID parameters were obtained. Table 1 shows the Ziegler Nichol's formula used for the PID parameters evaluation. Fig. 7 to Fig. 9 show the PID controllers designed, which are Ziegler Nichols, Robust PID with back calculation anti-windup and autotuned PIDs respectively.

Table 1 Ziegler Nichol's Parameters [8]

PID Type	*Kp*	*Ti = Kp/Ki*	*Td = Kd/Kp*
P	$\frac{\tau}{k\theta}$		
PI	$\frac{0.9\tau}{k\theta}$	$\frac{\theta}{0.3}$	
PID	$\frac{1.2\tau}{k\theta}$	2θ	0.5θ

Fig. 7 and Fig. 8 show the PID controllers design based on the collated data and transfer function obtained from the ARX modelling as well as using Ziegler Nichole's tuning formulae and time tracking constant Ta for the Robust PID with back calculation anti windup. Meanwhile, the PID with autotuning in Fig. 9 is based on the PID block in the Simulink Library, in which its PID values can be tuned to obtain a desired response. The evaluation of the performances of these PID controllers is discussed in the section 3.

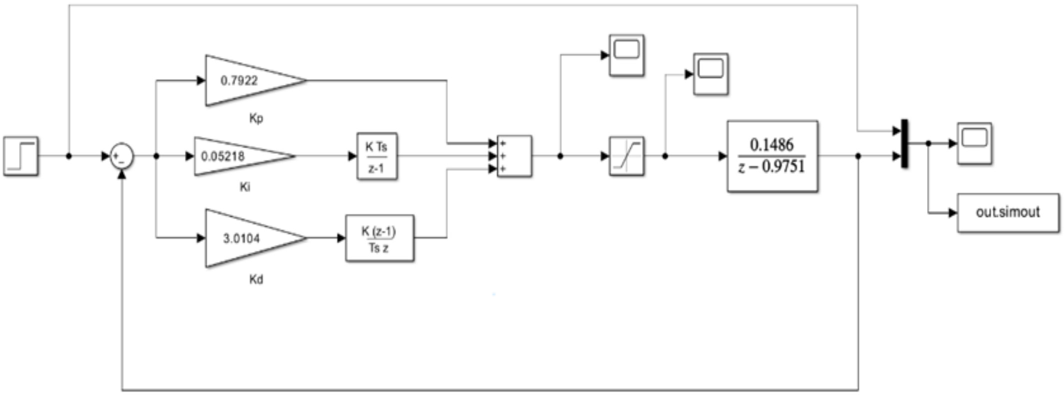

Fig. 7 *Ziegler Nichol's PID controller design*

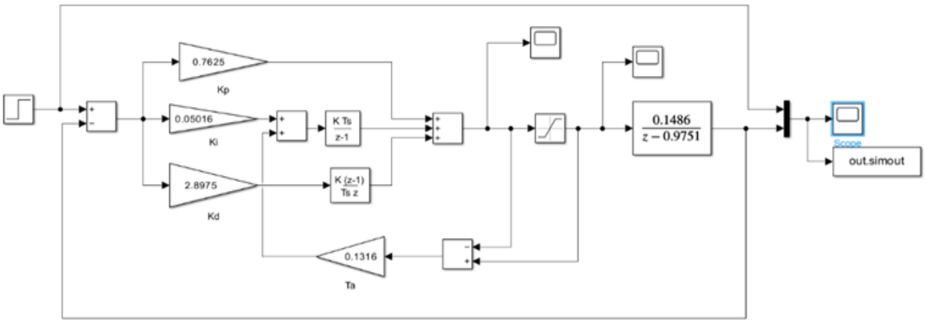

Fig. 8 *PID with back calculation anti windup*

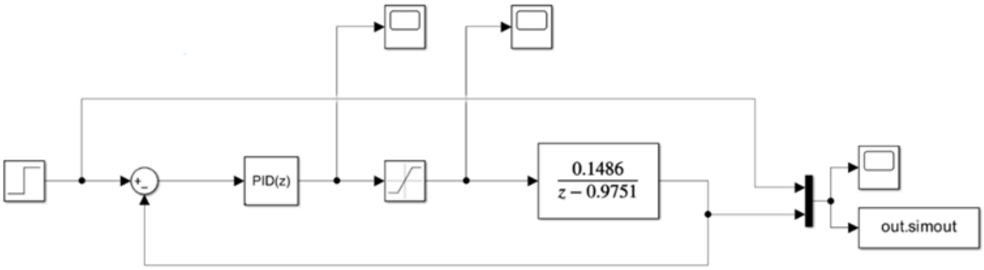

Fig. 9 *Autotuned PID*

3. Result and Analysis

This section shows the result of the study. It begins with data collection obtained from the dc motor, followed by the ARX modelling and PID simulation.

3.1 Interfacing and Data Collection

The outcome of this study commenced with the successful completion of the interfacing as shown in Fig. 4. Followed by the data collection obtained from the open loop model in Fig. 2, pairs of 31910 data each were obtained using a sampling time of 0.1ms on specified step input of 80% PWM which is the pulse width modulation (PWM) as shown in Fig. 10 and Fig. 11. Both figures show the plot of the input PWM along with its corresponding outputs, also known as the step response. The pairs of data obtained are necessary for the sole purpose of ARX modelling, hence, data for testing and validation of the testing needed to be obtained.

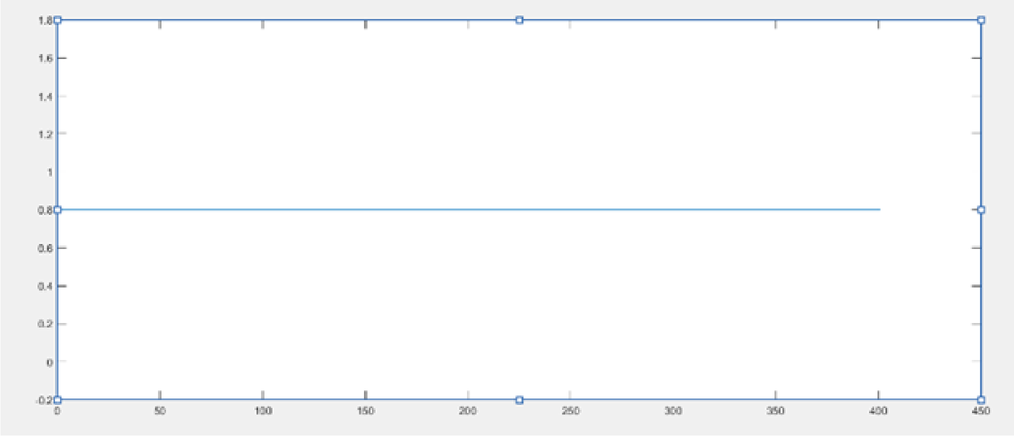

Fig. 10 *80% PWM*

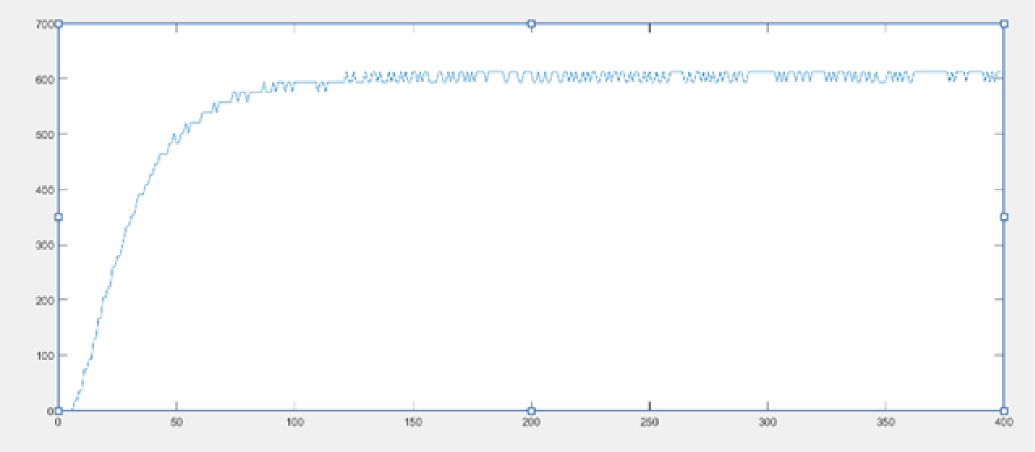

Fig. 11 *Step response at 80% PWM*

3.2 ARX modelling

Table 2 shows the result of the ARX modelling transfer functions in Z domain with their corresponding final prediction error, F.P.E and percentage best fit. It can be deduced that the percentage of best fits increases as the ARX order increases. However, the aim is to opt for the most suiting best fits with the most simplified transfer function to avoid bulkiness and complexity of the system. Thus, the first ARX order [1 1 1] was taken into consideration and chosen for the PID design later since it's befitting the requirement needed. Fig. 12 and Fig. 13 show the ARX modelling and the best fit percentages.

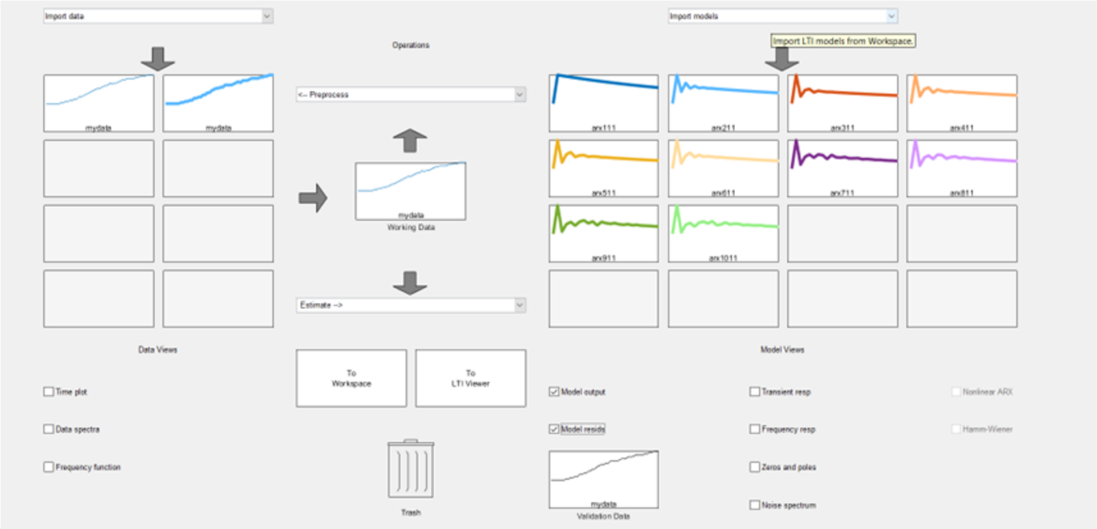

Fig. 12 *ARX modeling*

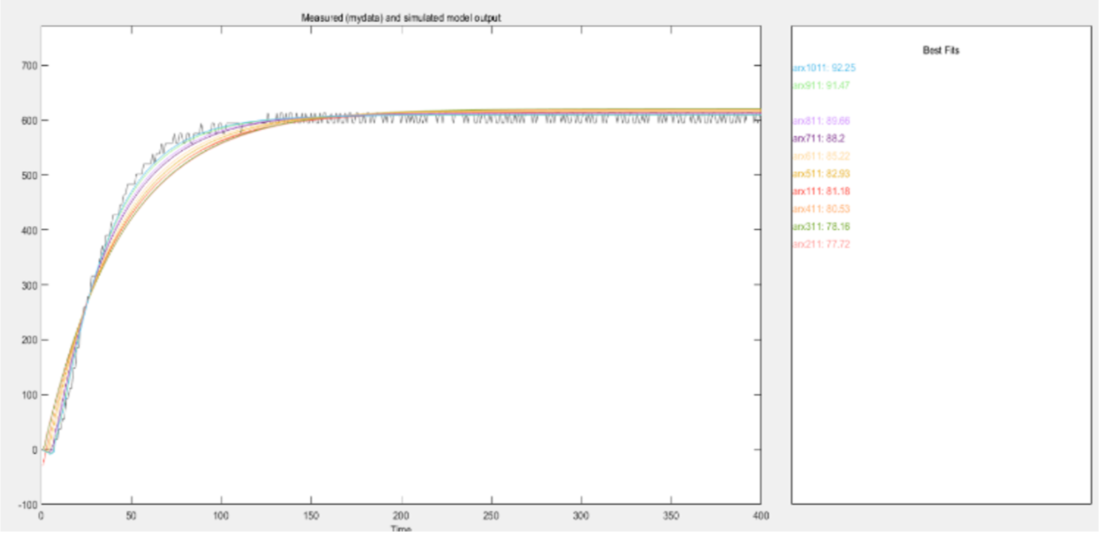

Fig. 13 *Percentage best fit*

Table 2 *ARX modelling and comparative studies*

ARX ORDERS [na, nb nk]	Z-DOMAIN TRANSFER FUNCTIONS	BEST FITS (%)
[1 1 1]	$\frac{0.1486z^{-1}}{1-0.9751z^{-1}}$	81.18
[2 1 1]	$\frac{0.2136z^{-1}}{1-0.4191z^{-1}-0.5455z^{-2}}$	77.72
[3 1 1]	$\frac{0.2811z^{-1}}{1-0.2824z^{-1}-0.4138z^{-2}-0.29127z^{-3}}$	78.16
[4 1 1]	$\frac{0.28127z^{-1}}{1-0.2525z^{-1}-0.44227z^{-2}-0.3262z^{-3}+0.06771z^{-4}}$	80.53
[5 1 1]	$\frac{0.2909z^{-1}}{1-0.2224z^{-1}-0.4529z^{-2}-0.3656z^{-3}+0.02404z^{-4}+0.06545z^{-5}}$	82.93

3.3 PID Performance

Tables 3 and 4 show the labelled parameters of k, θ and τ, as well as the Ziegler Nichol' s PID parameters.

Table 3 *Ziegler Nichol's PID parameters*

Controller	Gain	Values	
PID	*Kp*	*0.7625*	
	Ki	*0.05016*	*Ti =15.2 secs*
	Kd	*2.8975*	*Td = 3.8 secs*

Table 4 *Labelled Parameters*

Labelled parameters	Values
Process gain, K	*5.9223*
Time delay, θ	*7.6 secs*
Time constant, τ	*28.6 secs*

Based on section 2.3, the PID parameters for ZN PID were calculated as shown in Table 3. Meanwhile Table 4 shows the process parameters obtained, the time tracking constant of the robust PID which is the square root of the product of the integral time Ti and derivative time Td as shown in equation (1). Thus, Ta = 7.6 secs, 1/Ta = 0.1316. These PID controllers were simulated for 4000 secs on a sampling time of 0.1ms. The following parameters for the PID are shown in table 3 and 4. Fig. 14 shows the Ziegler Nichol's, Robust and autotuned PIDs' simulation and result. Their respective overshoot, settling and peak time can be referred to from Table 5.

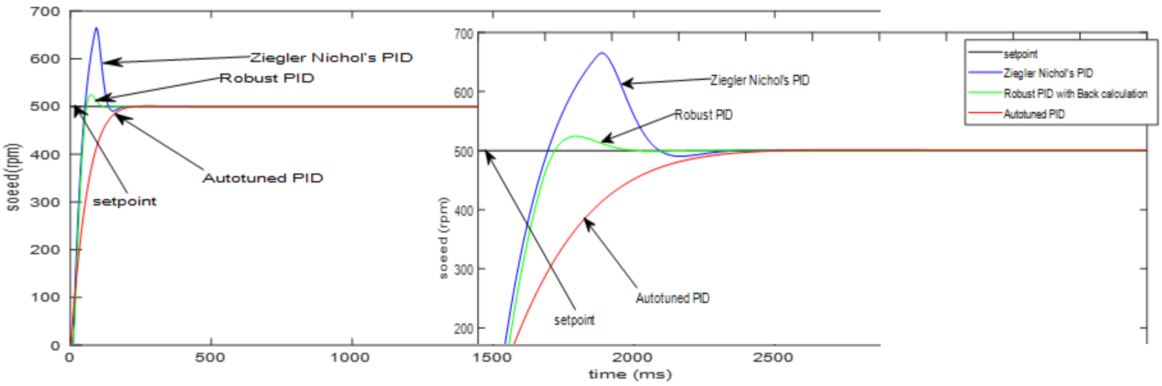

Fig. 14 *PID controllers' simulation result*

3.4 Comparative study between simulations of ZN-PID, robust PID and autotuned PID

Based on the simulations performed on the three PID controller designs, a comparison of the percentage overshoot, peak and settling time between these three PID controllers are expressed and illustrated in Table 5. From the Table 5, Ziegler Nichols performed well in both overshoot and settling time with over 32% and 50 secs with relatively high peak time of 140 seconds respectively while the robust PID performed quite good as well in terms of the overshoot of 5% and has a relatively large settling time with peak time of 100 and 230 secs respectively. Finally, the autotuned PID also performed the best and excellently in terms of all the three criteria with no overshoot, smallest settling and peak time and it was more stable and running within the setpoint range. Nonetheless, all the PIDs above performed greatly, at the end of the day, the criteria all depend on whatever is being required by engineers and this explains the importance, potentials and needs to explore PIDs, invented over 70 years back and still in use in today's world.

4. Conclusion

This project focused on the design and implementation of a PID controller to regulate the speed of a DC motor. The work began with setting up a hardware framework (i.e. interfacing) for data collection, then developed an ARX model to analyze motor behavior. The core of the project was design and evaluation of the PID controllers through simulation testing. Three PID controllers were designed, and their performances were evaluated accordingly based on their overshoot percentages, peak and settling time, all PID controllers performed excellently well as the autotuned PID was the best of the three, followed by the robust PID and finally the Ziegler Nichol's PID. The project marks a milestone in DC motor regulation and serves as a catalyst for ongoing research to optimize control strategies for modern industries.

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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 confirm contribution to the paper as follows: ***study conception and design:*** *Azeez Hazzan Adetayo;* ***data collection:*** *Azeez Hazzan Adetayo;* ***analysis and interpretation of results:*** *Azeez Hazzan Adetayo;* ***draft manuscript preparation:*** *Azeez Hazzan Adetayo, Mohd Hafiz A. Jalil@Zainuddin and Lukman Owolabi Afolabi. All authors reviewed the results and approved the final version of the manuscript.*

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