DC Motor Speed Control Using Dual Full-Bridge Driver in Proteus Simulation

Ekki kurniawan[1]*, Muhammad Yusuf Darmawan[2] and Anka Sidqi[2]

***Abstract*--Controlling the speed and direction of DC motor rotation is vital in various industrial and educational applications. However, many college students do not understand the characteristics and control of DC motors. Therefore, this study aims to study the simulation of DC motors using the L298 motor driver and Arduino platform with the help of Proteus software. This study focuses on the simulation of controlling the speed and direction of DC motors using a potentiometer as a speed controller and a switch to change the direction of motor rotation (clock and anti-clock). The ACS712 current sensor and voltage sensor are used to monitor the current, voltage, and power displayed on the LCD screen. By using Arduino as a microcontroller, this system allows precise control and real-time monitoring of the motor's electrical parameters. The simulation results show that the designed system can control the speed and direction of DC motors well and provide important information about the operational characteristics of the motor. This study not only offers theoretical insights but also practical applications in the development of efficient and effective motor control systems. Thus, this study is expected to be an essential reference for students, researchers, and practitioners in understanding and developing better motor control systems.**

***Index Terms*- DC Motor, Proteus Simulation, Arduino, Current and Voltage Sensors.**

NOMENCLATURE

DC	Direct Current
LCD	Liquid Crystal Display
PWM	Pulse Width Modulation
RPM	Rotation Per Minute

I. INTRODUCTION

Controlling the speed and direction of DC motor rotation is a crucial aspect of various industrial and educational applications. DC motors are often used because of their advantage in easier speed control compared to AC motors. However, a deep understanding of the characteristics and control of DC motors is still lacking among college and university students. This study aims to study the control of the speed and direction of DC motor rotation using the L298 motor driver and the Arduino platform. This simulation uses Proteus software to design and test a DC motor control system.

The circuit used in this study involves several main components, namely Arduino Uno as a microcontroller, L298 motor driver to control the direction and speed of the DC motor, potentiometer (RV1) as a speed regulator, and switches (Clock and AClock) to change the direction of motor rotation (clockwise and counterclockwise). In addition, current and voltage sensors are used to monitor the electrical parameters of the motor and display them on the LCD screen. This system is also equipped with a battery (BAT1) as a 12V power source, a DC motor as the main controlled component, and an LCD screen to display real-time readings of the motor current and voltage.

Current and voltage sensors allow real-time monitoring of motor current, voltage, and power, providing deeper insight into the operational characteristics of DC motors. This research will help students and researchers understand how to effectively control the speed and direction of DC motors and provide practical examples of using Arduino in control systems. Thus, the results of this study are expected to be an essential reference in developing and implementing more efficient and effective motor control systems. This simulation is expected to improve understanding of DC motor control and expand knowledge about Arduino applications in electronic and control systems. The results of this study are not only theoretically helpful but also provide practical applications in the fields of electrical and mechatronic engineering.

Several previous studies, including the work by Bernadeta Wuri Harini et al. [1], have examined DC motor speed control using the R method and manual calculations with a tachometer to assess the motor's speed and voltage accuracy. These studies highlighted fluctuations in current and inductance at varying motor speeds. In a separate study, Juwon Lee et al. investigated the effects of Pulse Width Modulation (PWM) waveforms on the DC motor's speed and torque, concluding that as motor torque increases, current rises, causing the motor's speed to decrease and take longer time to reach optimal performance [2]. Additionally, Subhendu Bikash Santra et al. focused on the relationship between speed and torque at 120-degree and 180-degree angles. Their findings showed that the motor's speed also increased as the input power load and angle increased [3]. Building on these previous works, this research uses linear regression and multiple analysis criteria to explore the DC motor's speed and current characteristics, employing three speed control settings at 100%, 80%, and 60% of the motor's rated value.

The rest of this paper is organized as follows: Section II provides a literature study, summarizing relevant previous research. Section III describes the system design and

1. Jl Batik Pekalongan No 11 Bandung 40123 Indonesia.
2. Department of Electrical Engineering, Telkom University, Bandung, Indonesia.
Corresponding author Email: ekkikurniawan@telkomuniversity.ac.id

experimental procedure used in this study. Section IV presents the results and discussion, analyzing the findings in detail. Section V concludes the study by summarizing the main findings, while Section VI outlines potential future works to build on this research.

II. LITERATURE STUDY

A. Literature Research

This study explores the literature by collecting interrelated references between system design and applied theories that are obtained and selected based on their relevance to existing research.

a. DC Motor Component

A DC motor is an electromechanical device that converts electrical energy into mechanical energy through the interaction of a magnetic field and an electric current. A DC motor has two components: the rotor, which produces rotation from electromagnetic induction, and the stator, which creates a magnetic field in the form of AC, which also induces the rotor part to rotate through electromagnetic induction. So that the rotor can still rotate when the electromagnetic induction is small, another component in the form of a commutator keeps the rotor spinning in the same or opposite direction. The rotation speed of a DC motor can be controlled by adjusting the voltage given to the DC motor [4].

b. DC Motor Speed and Direction Control

DC motor speed control can be achieved using the Pulse Width Modulation (PWM) method, where DC voltage is given to the motor in the form of pulses with varying signal widths [5]. The direction of rotation of a DC motor and the speed of the DC Motor can be changed by reversing the polarity of the applied voltage using an H-bridge circuit with the L298 motor driver as a reference [6].

c. L298 Motor Driver

The L298 motor driver is a motor control chip that is often used in robotics and automation applications. The L298 can independently drive two DC motors or a single stepper motor, using control inputs (IN1, IN2, IN3, IN4) to control the direction of motor rotation and enabler inputs (ENA, ENB) to control the motor speed via PWM [7].

d. Arduino Microcontroller

Arduino is an open-source microcontroller platform widely used for electronic prototyping and DIY projects. Arduino Uno, which uses an ATmega328 microcontroller, has 14 input/output pins, six of which can be used as PWM output and six analog input pins that can be used to connect sensors, actuators, and other devices [8].

e. Potentiometer

A potentiometer is a variable resistor used to adjust the voltage in a circuit. In motor speed control applications, a potentiometer is used to generate a reference voltage that is converted into a PWM signal by the microcontroller.

f. Switch

The switch in a DC motor controls the direction of the motor. The switch is used to change the control input to the motor driver, allowing changes in the motor's direction of rotation.

g. Proteus Software

Proteus is an electronic circuit simulation software used to design and test electronic systems before they are physically implemented. Proteus allows users to create circuit schematics, simulate circuit operations, and monitor circuit responses to various input conditions.

h. Mathematical Equations

Several basic mathematical equations are often used to understand and control motor behavior in DC motor control. The equations that depend on the activity of the DC motor are written below.

The DC motor voltage is calculated according to Ohm's Law, expressed as (1):

$$V = I.R \tag{1}$$

Where V is the voltage (in volts), I is the current (in amperes), and R is the resistance (in ohms).

The DC Motor Voltage is described as (2):

$$V_m = E + I_a.R_a \tag{2}$$

Where V_m is the motor terminal voltage, E is the back emf (electromotive force), Ia is the armature current, and Ra is the armature resistance.

The Motor Speed equation is described as (3):

$$\omega = \frac{V_m - I_a.R_a}{k_e} \tag{3}$$

Where ω is the angular velocity of the motor, and ke is the motor back voltage constant.

The Motor Torque is defined by (4):

$$T = k_t.I_a \tag{4}$$

Where T is the torque, and kt is the motor torque constant.

The Pulse Width Modulation (PWM) equation is described as:

$$V_{avg} = D.V_{in} \tag{5}$$

Where V_{avg} is the average voltage applied to the motor, D is the duty cycle (ratio of ON time to total period), and V_{in} is the input voltage.

This theoretical foundation provides a basis for understanding DC motor speed and direction control using Arduino and L298 motor driver. This knowledge will be applied in research to design, simulate, and test effective and efficient motor control systems.

B. Linear Regression

Definition criteria and explanation of R Square, Multiple R, Intercept, Adjusted R Square, and Standard Error.

a. R Square

R Square, or the coefficient of determination, quantifies the proportion of variance in the dependent variable that can be explained by the independent variables in the model. It ranges from 0 to 1, where 0 indicates that the model explains none of the variability and 1 indicates that it explains all the variability.

The Formula for R Square is:

$$R^2 = 1 - \frac{SS_{res}}{SS_{tot}} \quad (6)$$

SS_{res} is the sum of squares of residuals (the difference between observed and predicted values). SS_{tot} is the total sum of squares (the difference between observed values and the mean of the observed values [9].

b. Multiple R

Multiple R is the correlation coefficient that represents the correlation between the observed and predicted values of the dependent variable in a multiple regression model. It is the square root of R Square:

$$Multiple\ R = \sqrt{R^2} \quad (7)$$

This value also ranges from 0 to 1, with higher values indicating a stronger linear relationship between the observed and predicted values [10].

c. Intercept

The intercept in a regression equation represents the expected value of the dependent variable when all independent variables are equal to zero. It is denoted as b_0 in the regression equation:

$$y = b_0 + b_1x_1 + b_2x_2 + b_nx_n \quad (8)$$

Where y is the predicted value, b_0 is the intercept, and $b_1, b_2, \ldots, b_n$ are the coefficients for independent variables $x_1, x_2, \ldots, x_n$[9].

d. Adjusted R Square

Adjusted R Square modifies R-Squared to account for the number of predictors in the model. It provides a more accurate measure of model fit, especially when comparing models with different numbers of predictors. It can decrease if adding a new predictor does not improve the model sufficiently.

The formula for Adjusted R Square is:

$$Adjusted\mathbb{R}^2 = 1 - \left(\frac{(1-R^2)(n-1)}{n-p-1}\right) \quad (9)$$

Where n is the number of observations and p is the number of preditors [11].

e. Standard Error

The Standard Error of the regression estimates the average distance that the observed values fall from the regression line. It provides insight into the accuracy of predictions. The formula for the standard error of the estimate (SEE) is:

$$SEE = \sqrt{\frac{SS_{res}}{n-p-1}} \quad (10)$$

Where SS_{res} is the sum of squares of residuals, n is the number of observations and p is the number of predictors. In summary, these statistical metrics are crucial for evaluating the performance of a multiple regression model, helping to determine how well the model fits the data and the reliability of its predictions[12].

C. State of the Art or Taxonomy and Comparison

The state of the art for this research and the results of previous research will be explained in Table I.

TABLE I
State of The Art or Taxonomy for This Research

No.	Title	Author	Explanation
1	Pulse Width Modulation Methods for Minimizing Commutation Torque Ripples in Low Inductance Brushless DC Motor Drives (2023)	Juwon Lee, Gyu Cheol Lim, Jung-Ik Ha [2].	Relevance: This study provides insights into the PWM technique crucial for RPM control in this research. Understanding these techniques aids in refining PWM control for the dual full-bridge driver in proteus simulation.
2	Comparison of Two DC Motor Speed Observers on Sensorless Speed Control Systems (2022)	Bernadeta Wuri Harini, Martanto, Tjendro [1].	Relevance: This finding supports our research on how voltage and load affect RPMM with the dual full-bridge driver. It provides a comparative context for this result on speed control in proteus.
3	High Efficiency Operation of Brushless DC Motor Drive using Optimized Harmonic Minimization based Switching Technique (2022)	Subhendu Bikash Santra, Arunava Chatterjee, Debashis Chatterjee, Sanjeevikumar Padmanaban, Krishnatreya Bhattacharya [3].	Relevance: The comparison between brushless DC motors and traditional methods provides context for evaluating the effectiveness of the dual full-bridge driver approach in this research. It helps in understanding efficiency metrics and performance relevant to this research.

III. System Design and Experimental Procedure

This section describes the design used in this study for controlling the direction and speed of a DC motor using L298 Motor Driver, utilizing clock and anti-clock (aclock) signals to change the motor's rotation direction. This method includes system design, hardware used, system block diagram, and experimental procedures.

A. Research Flowchart

The research begins with preparing the Proteus software, followed by designing the Direction and Speed Controller system for the DC motor within the Proteus software. Before running the simulation, adjustments or settings are made for the input battery voltage variations, the speed controller potentiometer, and the load. Then, the switches are adjusted to set the rotation direction of the DC motor. The motor's rotation and current output values are recorded and analyzed using linear regression. The research stages to be carried out can be seen in Fig. 1 below.

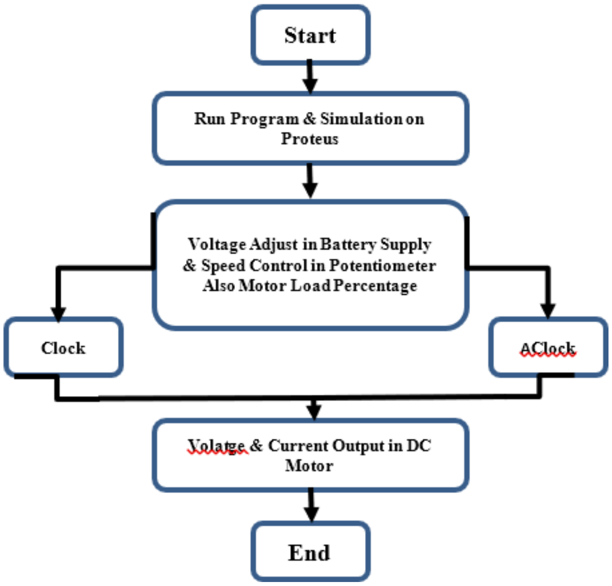

Fig. 1. Research Flow

B. System Design

In the design of this system, several hardware components are used to ensure proper functionality. First, the DC motor acts as the main actuator, driving the system based on the control signals received. The L298 motor driver serves as an intermediary between the microcontroller and the DC motor, enabling precise control over the motor's direction and speed. The microcontroller, represented by the Arduino Uno, acts as the system's brain, processing inputs from the potentiometer and the Clock and Aclock switches. The potentiometer is used to manually adjust the motor speed, while the switches allow for changes in the motor's rotation direction, whether clockwise or counterclockwise. The power source used to provide power is a DC battery.

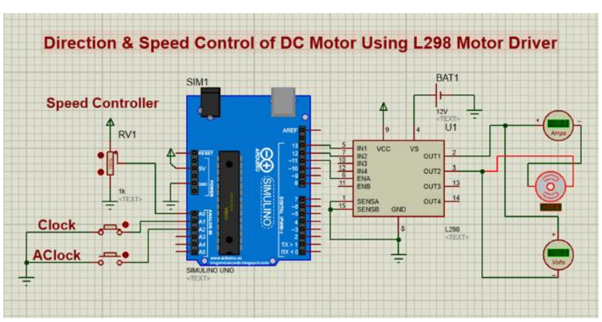

Fig. 2. Design System

C. System Block Diagram

The simulation circuit has three input variables: a potentiometer as the speed controller, a DC battery as the power source, and a button as a switch to change the motor's rotation direction. These three inputs are connected to a microcontroller, which functions as the system's brain. Then, the input parameters entering the microcontroller are forwarded to the L298 motor driver, and the output is measured using the DC motor and an ammeter.

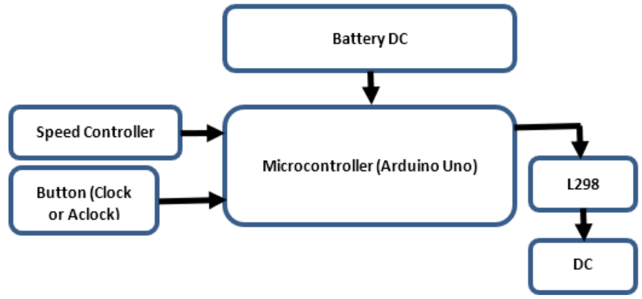

Fig. 3. System Block Diagram

D. Linear Regression

Linear regression is a highly useful tool for understanding and predicting the relationship between two variables by using the equation of a straight line that describes this relationship. By calculating coefficients and intercepts, a model can be formed that allows for making predictions and analyzing the relationship between the variables processed using linear regression [12]. In this study, linear regression is used as an analysis to determine the effect of input parameters on the output value of the system.

$$y = \beta_0 + \beta_1 x + \varepsilon \qquad (11)$$

y = dependent variable
β_0 = intercept, y value when x = 0
X = independent variable
β_1 = regression coefficient
ε = error

IV. Result and Discussion

This chapter presents the findings from the Proteus simulations conducted based on the design described in the previous chapter. The simulations explore the effects of different Speed Controller settings (100%, 80%, and 60%) on the DC motor's performance, including input voltage and load parameters variations.

A. Speed Controller 100%, 80% and 60%

Simulations were performed at three different speed controller settings on a DC motor (100%, 80%, and 60%). Each setting was tested with 10 data points to assess the influence of two independent variables, namely load (X1) and voltage (X2), on two dependent variables, namely motor speed (Y1, in RPM) and current (Y2, in mA). Linear regression analysis was used to interpret the results.

a. Speed Controller 100%

Table II
Simulation Data Test at Speed Controller 100%

No	X1 (%)	X2 (V)	Y1 (RPM)	Y2 (mA)
1	59	1,4	43,5	62,7
2	82	2,5	33	150
3	40	3,2	150	100
4	30	2	111	47,6
5	77	1,7	28,8	96,7
6	69	2,8	64,9	144
7	32	3	161	76,1
8	21	2	126	34,5
9	2	1	81,4	1,67
10	1	1,8	148	1,52

The statistical analysis results and linear regression equations obtained from these simulation data are presented in Table III.

TABLE III
The Value of Regression Analysis at Speed Controller 100%

	Current (mA)	RPM
R Square	0,957	0,938
Multiple R	0,978	0,97
Intercept	-49,3	57,54
Adjusted R Square	0,94	0,92
Standard Error	12,29	14,38
X1 (%)	1,37	-1,603
X2 (V)	29,93	48,33

Linear regression equations for the speed controller set to 100%:

$Y(RPM) = -1{,}603\,X1 + 48{,}33\,X2 + 57{,}534$

$Y(mA) = 1{,}374\,X1 + 29{,}93\,X2 - 49{,}30$

Analysis shows that voltage (X2) significantly impacts rotational speed, with each 1 V increase in voltage resulting in a 48,33 RPM increase. Both voltage (X2) and load (X1) positively affect current, with voltage having a stronger effect.

b. Speed Controller 80%

TABLE IV
Simulation Data Test at Speed Controller 80%

No.	X1 (%)	X2 (V)	Y1 (RPM)	Y2 (mA)
1	15	3	108	43,5
2	38	5	74,6	108
3	45	7	81,9	113
4	26	4,5	103	68,8
5	67	1,2	6,18	23,8
6	21	2,1	58,6	29,3
7	12	5,7	234	59,5
8	8	4	199	42,2
9	7	3,2	166	31,7
10	25	1,2	28,3	22,6

The statistical analysis results and linear regression equations obtained from the simulation data in Table IV are presented in Table V.

TABLE V
The Value of Regression Analysis at Speed Controller 80%

	CURRENT (mA)	RPM
R Square	0,854	0,75
Multiple R	0,924	0,86
Intercept	-17,93	114,35
Adjusted R Square	0,813	0,68
Standard Error	14,332	41,76
X1 (%)	0,567	-2,72
X2 (V)	15,49	17,16

Linear regression equations for the speed controller set to 80%:

$Y(RPM) = -2{,}72\,\mathrm{X1} + 17{,}16\,\mathrm{X2} + 114{,}35$

$Y(mA) = 0{,}567\,\mathrm{X1} + 15{,}49\,\mathrm{X2} - 17{,}93$

The impact of voltage (X2) on RPM remains significant but less pronounced compared to the 100% setting. The influence of load and voltage current is more balanced at 80% compared to 100%.

c. Speed Controller 60%

TABLE *VI*
Simulation Data Test at Speed Controller 60%

No.	X1 (%)	X2 (V)	Y1 (RPM)	Y2 (mA)
1	20	5	59	48,3
2	22	12	125	102
3	30	15	110	133
4	50	8	26,5	86,5
5	90	20	7,64	194
6	40	7	34,1	64,3
7	10	14	311	111
8	10	19	425	136
9	30	3,3	24,2	29,4
10	8	2	52,6	13,4

The statistical analysis results and linear regression equations obtained from the simulation data in Table VI are presented in Table VII.

TABLE *VII*
The Value of Regression Analysis at Speed Controller 60%

	CURRENT (mA)	RPM
R Square	0,989	0,88
Multiple R	0,994	0,94
Intercept	-5,085	76,43
Adjusted R Square	0,986	0,85
Standard Error	6,39	54,04
X1 (%)	0,53	-4,63
X2 (V)	7,64	17,53

Linear regression equations for the speed controller set to 60%:

$Y(RPM) = -4{,}63\,\mathrm{X1} + 17{,}53\,\mathrm{X2} + 76{,}43$

$Y(mA) = 0{,}53\,\mathrm{X1} + 7{,}64\,\mathrm{X2} - 5{,}085$

At 60%, the effect of load (X1) on RPM is pronounced compared to voltage (X2). Voltage remains a dominant factor in determining current but with a reduced impact compared to higher speed settings.

i. Effect of Load (X1) on Rotational Speed (Y1)

An increase in load (X1) consistently reduces rotational speed (Y1) across all speed controller settings. The most pronounced effect is observed at the 60% speed setting, with a confidence of -4,63. This contrasts with -2,72 at 80% and -1,603 at 100%, indicating a stronger sensitivity to load at low-speed settings.

ii. Effect of Voltage (X2) on Rotational Speed (Y1)

Voltage (X2) exerts a strong positive effect on rotational speed (Y1). The most significant impact occurs at the 100% speed setting, with a coefficient of 48,33. This effect diminishes at 80% (coefficient 17,16) and 60% (coefficient 17,53), showing that the effect of voltage on speed is less pronounced at lower speed settings.

iii. Effect of Load (X1) on current (Y2)

Load (X1) consistently increases current (Y2), but its effect is smaller compared to the effect of voltage (X2) at all speed controller settings. The highest load coefficient for current is 1.374 at 100%, followed by 0.567 at 80% and 0.53 at 60%, indicating a decreasing load influence on current with lower speed settings.

iv. Effect of Voltage (X2) on current (Y2)

Voltage (X2) has a significant positive effect on current (Y2). The effect is the strongest at 100% (29.93), decreases at 80% (15.49), and is lowest at 60% (7.64), demonstrating that voltage is a crucial factor in determining current.

The R Square value indicates that the regression model is highly effective in explaining the variability of the data, especially for the current (Y2) across all speed controller settings, with values close to 1. The Multiple R confirms a strong linear relationship between the input and output variables, peaking at 100% and slightly decreasing at the 80% and 60% settings. The Adjusted R Squared provides a slightly lower value than R Squared, accounting for the number of input variables and confirming the model's validity. A smaller Standard Error signifies more accurate model predictions, with the 100% speed controller setting offering the most precise predictions compared to 80% and 60%.

At lower speed settings (60% or 80%), the system experiences instability in current and voltage due to lower control sensitivity. This instability arises because the potentiometer in the speed controller is less responsive at these lower settings. In contrast, at the 100% setting, the potentiometer operates in a more linear and stable range, resulting in more consistent voltage and current.

Additional capacitors are needed so that the current on the motor does not fluctuate.

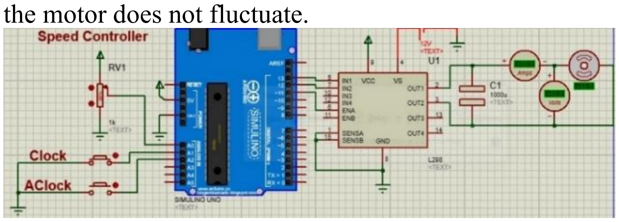

Fig. 4. Design System with Capacitor

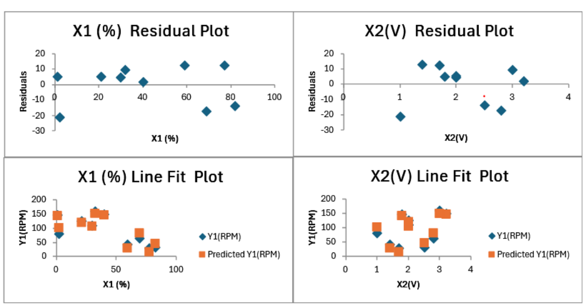

Fig. 5. Regression Graph at RPM in 100% Load

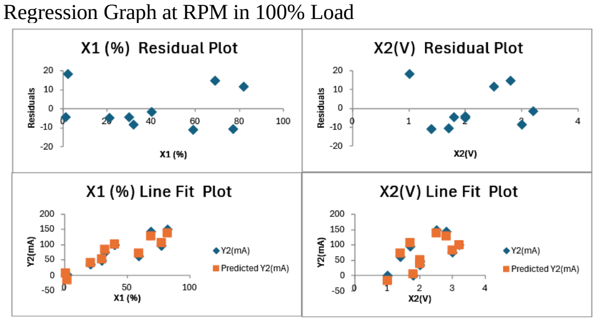

Fig. 6. Regression Graph at Current in 100% Load

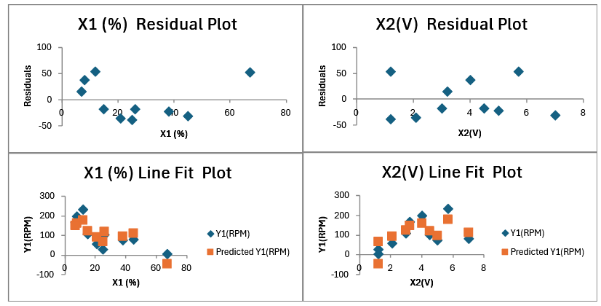

Fig. 7. Regression Graph at RPM in 80% Load

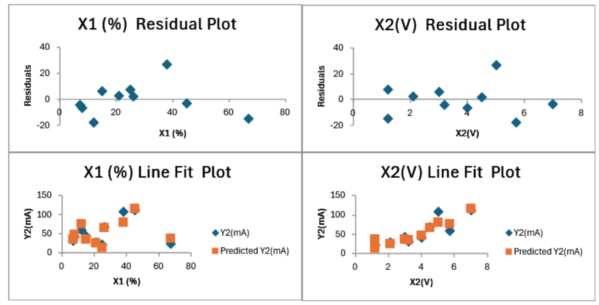

Fig. 8. Regression Graph at Current in 80% Load

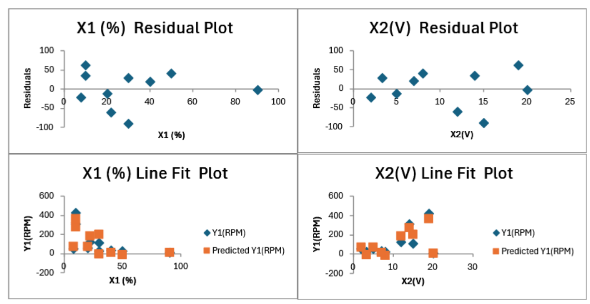

Fig. 9. Regression Graph at RPM in 60% Load

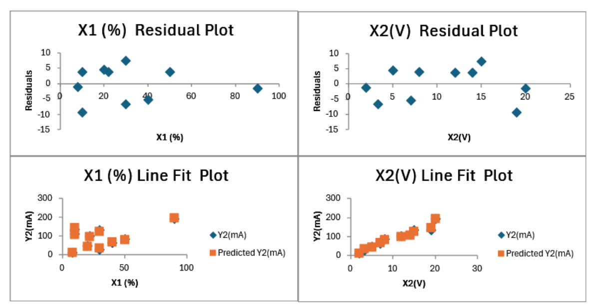

Fig. 10. Regression Graph at Current in 60% Load

Linear regression analysis graphs are crucial for visualizing the relationships between variables in the DC motor simulation using the L298 driver and Arduino platform. Key graphs likely include:

- RPM vs Load percentage and Voltage (X1 and X2): Illustrates how motor RPM changes with load percentage and voltage variations, using regression lines to depict these relationships.
- Current vs. Load Percentage and Voltage (X1 and X2): Shows how the current required by the motor responds to load percentage and voltage changes, also employing linear regression techniques.

Interpretation

- The regression coefficients highlight the sensitivity of outputs to changes in each input. For example, a high coefficient for voltage indicates a strong responsiveness of motor speed to changes in voltage.
- The R-squared value assesses the model's ability to explain data variability; higher R-squared values suggest a better model fit.

V. CONCLUSION

The study confirms the effective control of DC motor speed and direction using the L298 motor driver and Arduino platform. Simulations conducted with Proteus software demonstrate the practical implementation of these components in industrial and educational settings. Key elements include the Arduino Uno microcontroller, the L298 motor driver for control, a potentiometer for speed adjustment, switches for direction changes, and current and voltage sensors for real-time monitoring displayed on an LCD screen.

The simulation results validate the system's ability to control DC motor speed and direction with high precision and reliability. Linear regression analysis shows an impressive R-squared value of 95.7% for current (mA) and 93.8% for RPM at a 100% speed setting, indicating that the model accurately explains output variability based on input variables (load percentage (X1) and voltage (X2)). For example, a 1% increase in load leads to a 1.373 mA increase in current, while a 1V increase in voltage results in a 29.93 mA increase in current. Similarly, motor speed decreases by 1.603 RPM per 1% increase in load and increases by 48.33 RPM per 1V increase in voltage. These findings underscore the robust relationship between input variables and motor performance, contributing significantly to effective motor control systems development.

FUTURE WORKS

Future work could refine the existing PID control system to improve DC motor speed and direction control precision. Specific areas of investigation include Adaptive PID Controller and Tuning Methods, aiming to enhance system performance under varying load conditions and achieve optimal control response. Additionally, integrating IoT could enable real-time monitoring and remote adjustments, improving operational flexibility, data-driven optimizations, and predictive maintenance through cloud-based systems.

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