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TMS320F28379D microcontroller for speed control of permanent magnet direct current motor

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ABSTRACT

This paper aims to study the behavior of the proportional integral derivative (PID) and the fuzzy-based tuning PI-D controller for speed control of a permanent magnet direct current (PMDC) motor. The proposed method used a fuzzy-based tuning PI-D controller with a MATLAB/Simulink program to design and real-time implement a TMS320F28379D microcontroller for speed control of a PMDC motor. The performance of the study designed fuzzy-based tuning PI-D and PID controllers is compared and investigated. The fuzzy logic controller applies the controlling voltage based on motor speed errors. Finally, the result shows the fuzzy-based tuning PI-D controller approach has a minimum overshoot, and minimum transient and steady state parameters compared to the PID controller to control the speed of the motor. The PID controllers have poorer performance due to the non-linear features of the PMDC motor.

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1. INTRODUCTION

At present, permanent magnet direct current (PMDC) motors are an electrical machine that has been applied in many applications to drive mechanical mechanisms [1], [2]. Tasks that require speed control, position, or torque of the mechanical load. The power supply is alternating current; the current must be rectified to direct current first. In most robots, it is popular to use PMDC motors that are easy to control, provide high torque, and, most importantly, use batteries as electric power feeds. The built-in speed controller, torque, and position can use a variety of microcontroller boards and a variety of algorithms for accurate, fast, and stable control. PMDC motors are used in various industrial applications and robots [3] to control the rotational speed. The voltage input to the motor is controlled using a chopper control method that can control the speed and torque well.

The proportional integral derivative (PID) controllers [4]–[6] are used for automatic process control and robotics in industries. PID controllers are the most popular controllers in both the process and manufacturing industries. Furthermore, according to research on PID controllers, about ninety percent (90%) of process industries [7] employ PID as controllers. The PID controller [8] has simplicity, stability, and robustness; it is a type of controller that is most widely applied. This popularity is a result of their robustness, simplicity, and ease of retuning control parameters. The PID controller has been conventionally regarded as the best controller in the absence of fundamental process knowledge.

Fuzzy logic controller [9]–[11] are the science of computing of calculations that play a greater role in the field of research computer and can be applied in many different jobs such as medical, military, business, and industry. The research study to understand the science of fuzzy logic and deep neural networks, which are to be applied in various fields, is becoming more and more in demand. The computer system that has the ability to automatically adjust the system according to the environment has changed, making smarter, more human-like decisions so that humans can solve problems that were not previously solved by using old knowledge that was learned and applied to effectively solve problems.

The design of the MATLAB Simulink embedded coder for TMS320F28379D [12], which is the program used for the development and control of programming algorithms by using a set of diagrams, is ready-made in the Simulink library. By selecting the target support package, you will find a chip support library consisting of ready-made diagrams such as analog-to-digital converter (ADC), enhanced quadrature encoder pulse (eQEP), and enhanced pulse width modulator (ePWM). For compilation, it can be used with the composer studio code program, also called the CCS program. By creating code at the location of the CCS program, the real-time working part of the MATLAB/Simulink program, this CCS program will be compiled into the C language first. It then converts the data into machine language for the controller. Digital signals from the TMS320F28379D microprocessor board can be debugged into programs through the joint test action group (JTAG) emulator to store data in registers without having to compile the program. There are many research articles showing how to control the speed and position of a DC motor using a simulator. The first step is to find the parameters using MATLAB to solve the control and display problems, and the TMS320F28379D board with MATLAB program is used for real-time use [13].

The DC-to-DC converter, also called chopper circuits, is a circuit that is commonly used in industrial applications and computers. A chopper circuit involves changing a DC power supply from one voltage to another. It consists of power electronic devices such as bipolar junction transistor (BJT), silicon controlled rectifier (SCR), insulated gate bipolar transistor (IGBT), or gate turn-off thyristor (GTO); which act as switches controlling the duty cycle of the output waveform, making it possible to control the average value of the output voltage of the chopper circuit helps to control the acceleration or Speed of DC electric motor to be highly efficient, smooth and responsive to move quickly This makes the chopper circuit [14] suitable for many types of work, such as the braking of DC electric motors. To return energy to the supply and resulting in saving energy. The chopper may act as a source that converts the DC voltage down, or it may act as a source that converts the DC voltage to a higher level.

The paper presents the following topics. The mathematical modeling and control objectives are described in section 2. In section 3, the experimental study of controller systems such as PID controllers and adaptive PI-D controllers is carried out. The fuzzy dressings [10], [11], [15] are respectively designed. In section 4, the designed controller testing methods are applied to the PMDC motor model, along with the experimental results [16], [17]. Finally, the results of the experiment are summarized in section 5.

2. RESEARCH METHOD

2.1. The mathematical modelling of permanent magnet direct current motor

PMDC motor uses permanent magnets located in the stator to provide the magnetic field instead of it being created in stator windings. The equivalent circuit diagram of the PMDC motor [18] is the electromechanical system consisting of electrical and mechanical components as shown in Figure 1.

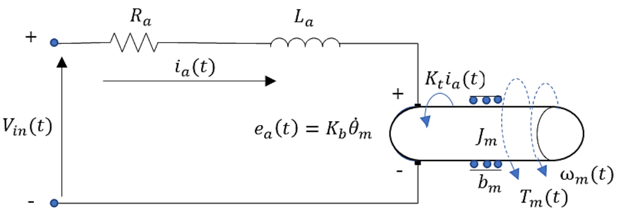


Figure 1. The equivalent circuit diagram of the PMDC motor

When a voltage is applied to the armature winding, it creates a magnetic field in the armature winding and interacts with the permanent magnetic field in the stator to create torque in the armature, as shown in (1).

$$T_m = K_t i_a \quad (1)$$

Where T_m is the developed torque in the motor, K_t is the torque constant, and i_a is the armature current. The armature winding intersects with the result of the magnetic field and creates a back electromotive force (EMF) in the armature winding, as shown in (2).

$$e_a(t) = K_b \frac{d\theta_m(t)}{d_t} = K_b\omega_m \quad (2)$$

where e_a is the back EMF, K_b is the EMF constant, and ω_m is shaft angular velocity. Applied Kirchhoff's law of input voltage as (2):

$$V_{in}(t) = R_a i_a(t) + L_a \frac{di_a(t)}{dt} + K_b \frac{d\theta_m(t)}{d_t} \quad (3)$$

where R_a is the armature resistance, L_a is the armature inductance, θ_m is the motor shaft output angle, and V_{in} is the input voltage. Taking Laplace transform in (3), given as in (4)

$$V_{in}(s) = R_a I_a(s) + L_a s I_a(s) + K_b s \theta_m(s) \quad (4)$$

The transfer function of the PMDC motor is as (5) and (6):

$$\frac{I_a(s)}{[V_{in}(s) - K_b \omega(s)]} = \frac{1}{(L_a s + R_a)} \quad (5)$$

$$I_a(s) = \frac{[V_{in}(s) - K_b \omega(s)]}{(L_a s + R_a)} \quad (6)$$

The mechanical mathematical model is the sum of the torques, shown as (7):

$$K_t I_a(s) = (J_m s + b_m) s \theta(s) + T_L(s) \quad (7)$$

where T_L is the load torque, J_m is the inertia of the motor, and b_m is the damping friction, the mechanical component transfer function is given by (8).

$$\frac{\omega_m(s)}{K_t I_a(s) - T_L(s)} = \frac{1}{J_m s + b_m} \quad (8)$$

If $T_L = 0$, we have

$$\frac{\omega_m(s)}{K_t I_a(s)} = \frac{1}{J_m s + b_m} \quad (9)$$

Then:

$$K_t I_a(s) = (J_m s + b_m) s \theta(s) \quad (10)$$

The relationship between the input voltage and the motor shaft output angular velocity of the PMDC motor without a load attached is shown in (11).

$$\frac{\omega_m(s)}{V_{in}(s)} = \frac{K_t}{[(L_a s + R_a)(J_m s + b_m) + K_t K_b]} \quad (11)$$

The simplification of the open-loop transfer function of the PMDC motor without load is shown in (12).

$$\frac{\omega_m(s)}{V_{in}(s)} = \frac{K_t}{[(R_a J_m)s + (R_a b_m) + K_t K_b]} \quad (12)$$

Consider in (12), the transfer function relationship between the input voltage and the rotational speed of the motor as shown in Figure 2. Next is a reference to Table 1 shows the electrical properties of the PMDC motor used in the experimental study. Then Table 2 explains the mechanical properties of the PMDC motor.

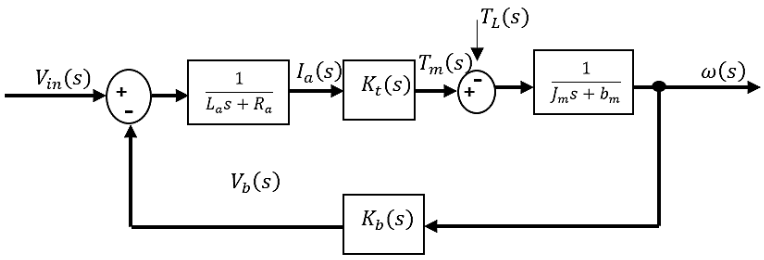


Figure 2. The block diagram of the PMDC motor

Table 1. The electrical properties of PMDC motor

Parameter	Value
Nominal voltage	24 V
Rate power input	100 W
No load speeds	3500 rpm
No load currents	0.55 A
Nominal current	3.1 A
Electric resistance	2.1 Ω
Electric inductance	0.035 mH
Back EMF constant	0.006 V/rpm

Table 2. The mechanical properties of PMDC motor

Parameter	Value
Moment of inertia	0.00025 Nm/rad/s^2
Friction coefficient	0.0002 Nm/rad/s
Torque constant	0.057 Nm/A

2.2. Fuzzy-based tuning PI-D controller structure

The PID controller cannot tune the parameters of the plant control and cannot be adjusted when the electric motor operates in a non-linear manner. Hence, fuzzy-based tuning of PI-D is necessary to automatically tune the PI-D parameters. The proposed controller is shown in Figure 3.

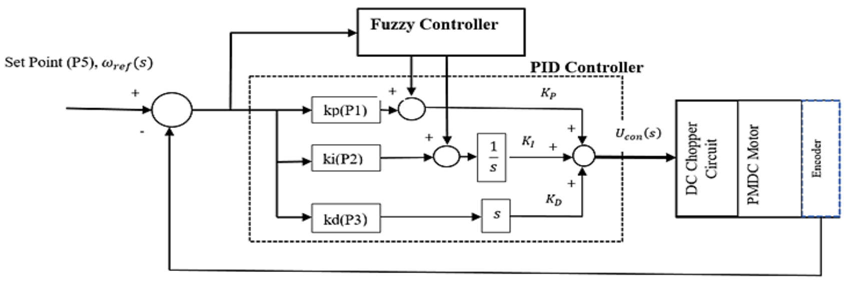


Figure 3. Block diagram of the fuzzy-based tuning PI-D controller

The output of the fuzzy-based tuning PI-D controller is given in (14)

$$U_{cont}(t) = K_P e(t) + K_I \int_0^t e(t)dt + K_D \frac{d}{dt} e(t) \quad (14)$$

With its Laplace transform:

$$U_{con}(s) = K_P + \frac{K_I}{s} + K_D s \quad (15)$$

By using backward Euler methods for both the integral and derivative terms, the resulting discrete-time PID controller is represented in (16):

$$U_{con}(\mathrm{z}) = \mathrm{K_P} + \frac{\mathrm{K_I T_S z}}{\mathrm{z-1}} + \frac{\mathrm{K_D N(z-1)}}{\mathrm{(1+NT_S)z-1}} \quad (16)$$

Details of the fuzzy logic controller [19]–[21] are shown in Figure 4, where there are two inputs to the fuzzy inference: e , and Δe. And two outputs: K_{Pf} , and K_{If}. The parameters k_1, k_2, α and β are input/output scaling factors. To determine the domain of each PI-D parameter [22]. The parameters of PI were defined as: $K_P \in (0,100)$, $K_I \in (0,1)$. Thus, the scales of the fuzzy interval (0, 1) as follows:

$$K_P = \alpha K_{Pf} + P_1 \quad (17)$$

$$K_I = \beta K_{If} + P_2 \quad (18)$$

$$K_D = P_3 \quad (19)$$

where, $\alpha = 0.15$, $\beta = 40$, P_1, P_2 and P_3 is external gain input.

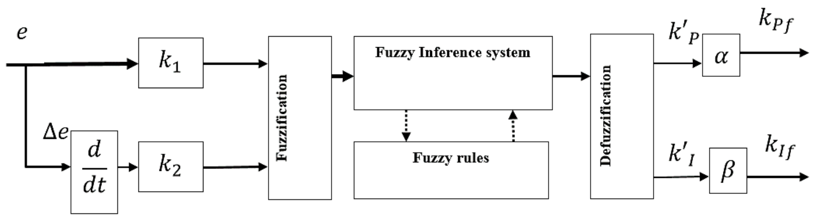
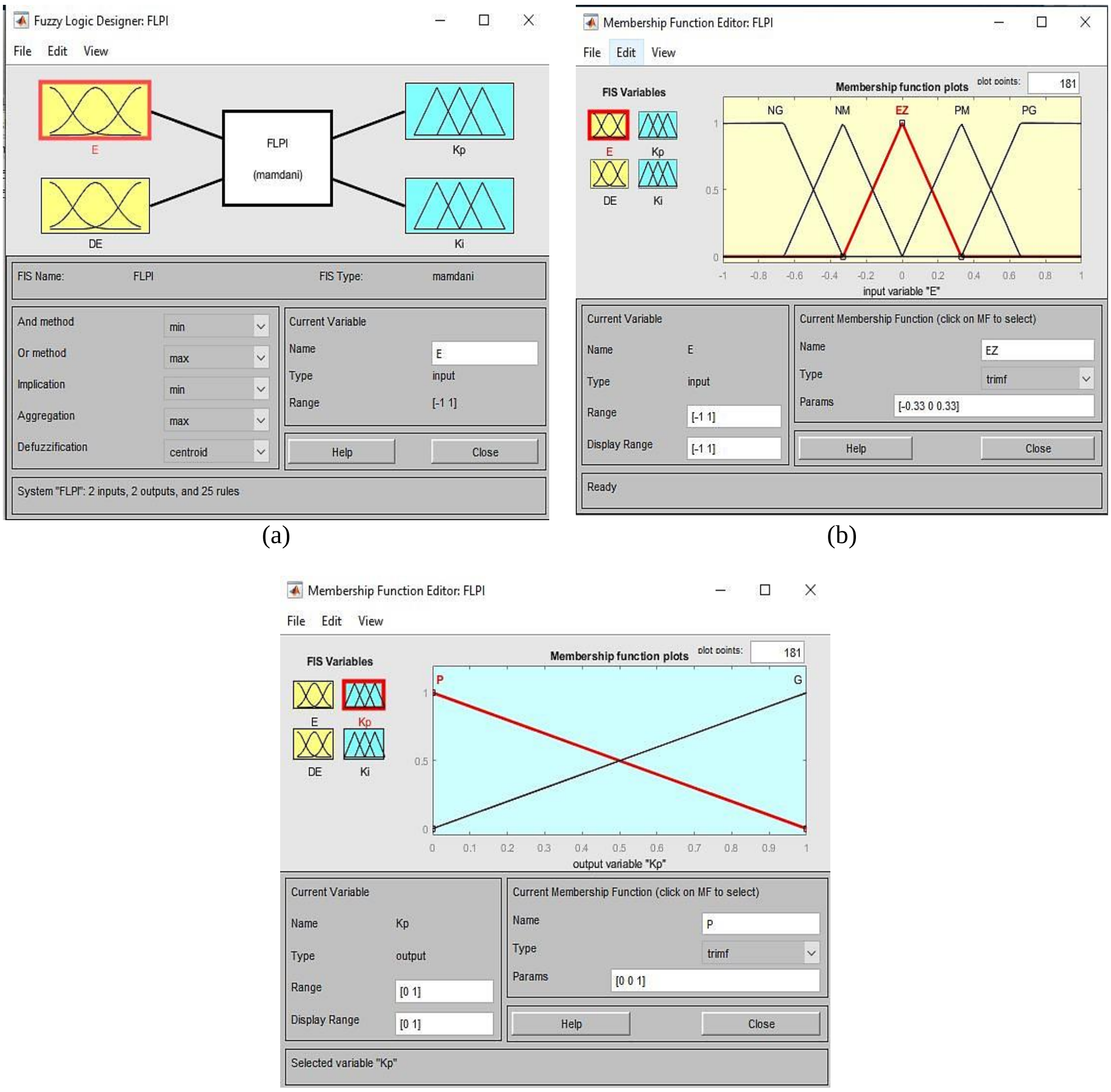


Figure 4. Structure of thr fuzzy logic controller

A fuzzy logic controller has four main components fuzzification interface, inference mechanism, rule base, and defuzzification interface. It consists of three membership functions with two inputs and one output. Each membership function consists of two trapezoidal memberships and five triangular memberships. Figure 5 shows the membership function of fuzzy input controllers. Figure 5(a) is the FIS editor. Figure 5(b) is membership function of error as input. Figure 5(c) is the membership function of ang_in_error as input. The surface viewers and rules of K_P and K_I are shown in Figure 6.



(a) (b)

(c)

Figure 5. Membership function of fuzzy input controllers; (a) the FIS editor, (b) membership function of error as input, and (c) membership function of ang_in_error as input

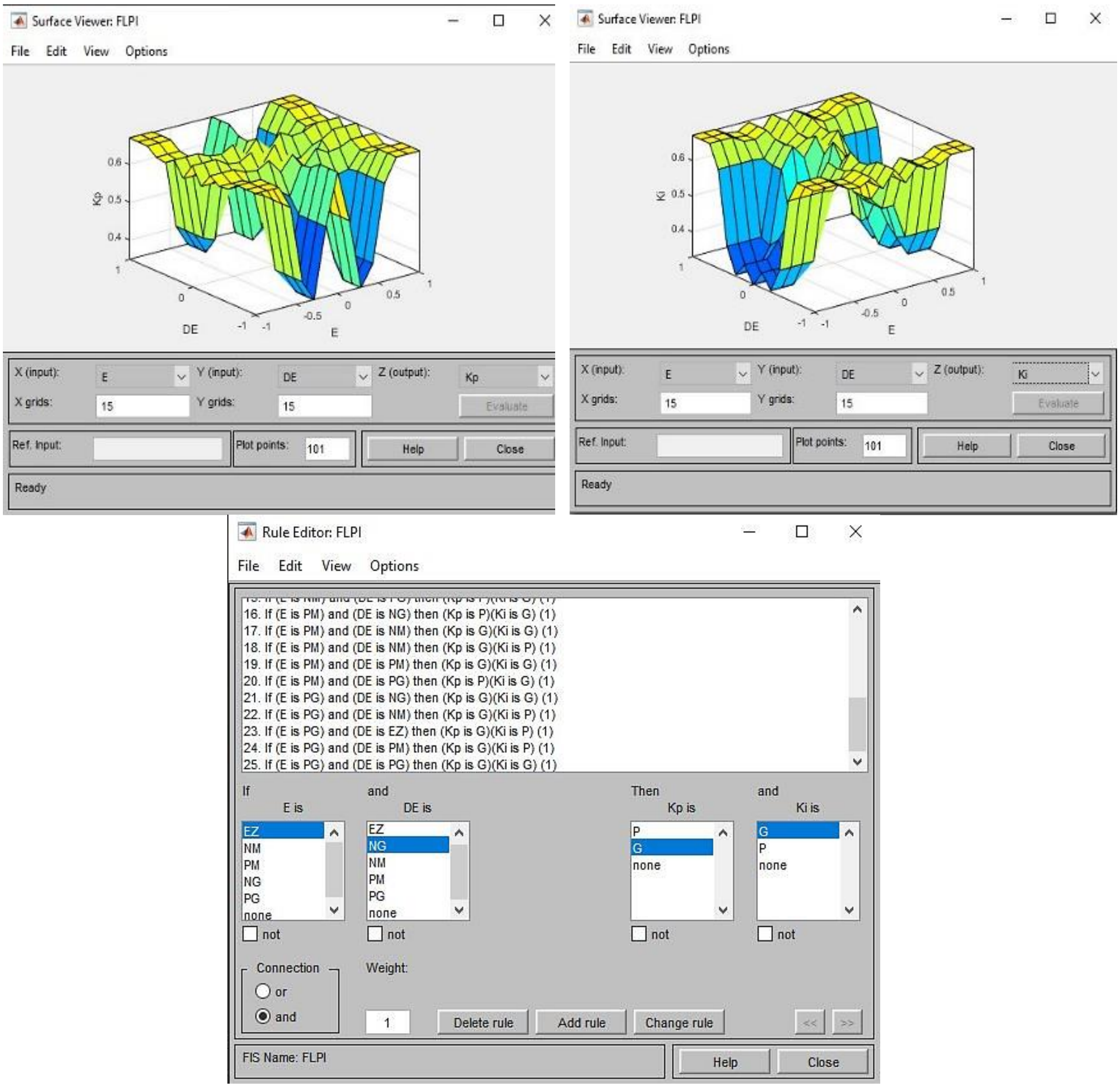


Figure 6. Surface viewer and rules

2.3. Chopper circuit

In the operation of the chopper, shown in the circuit diagram of the chopper in Figure 7, the circuit is using control of the on-off period. During operation of the period, the chopper [23] is on, and the output voltage is equal to the source voltage. When the chopper is off and the output voltage is zero. The average voltage shown is the following:

$$V_o = \left(\frac{T_{on}}{(T_{on}+T_{off})}\right)V_1 \tag{20}$$

$$V_o = \left(\frac{T_{on}}{T}\right)V_1 \tag{21}$$

$$V_o = \alpha V_1 \tag{22}$$

$$V_o = f T_{on} V_1 \tag{23}$$

where T_{on} is on-time, T_{off} is off-time, $T = T_{on} + T_{off}$ is chopping period, α is duty cycle percent, $f = \frac{1}{T}$ is chopping frequency, V_o is output voltage, and V_1 is source voltage.

Figure 7 shows the circuit diagram for the PMDC motor. The step-down chopper consists of IGBT switch (M2) and a diode (DF). A DC voltage source of input voltage (V1) is connected at the input, while a PMDC motor is connected at the output.

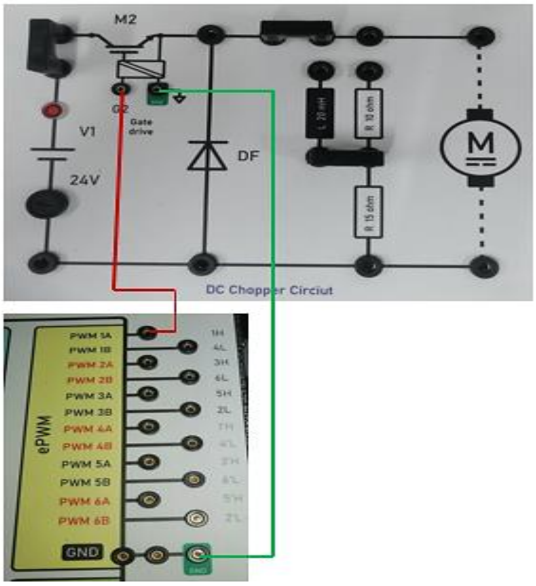


Figure 7. Circuit diagram of step-down chopper with PMDC motor connection

3. EXPERIMENT OF PROPOSED METHOD

3.1. Experimental platform practice

The experiment platform model [24]–[26] circuit is made up of a PMDC motor with an encoder to detect the speed of the motor. The connection of the personal computer to the TMS320F28379D board for the generation of pulse control to the chopper circuit drive and education practice set. When the electrical circuit is complete, open the MATLAB program. Perform a test on the specified program as shown in Figure 8.

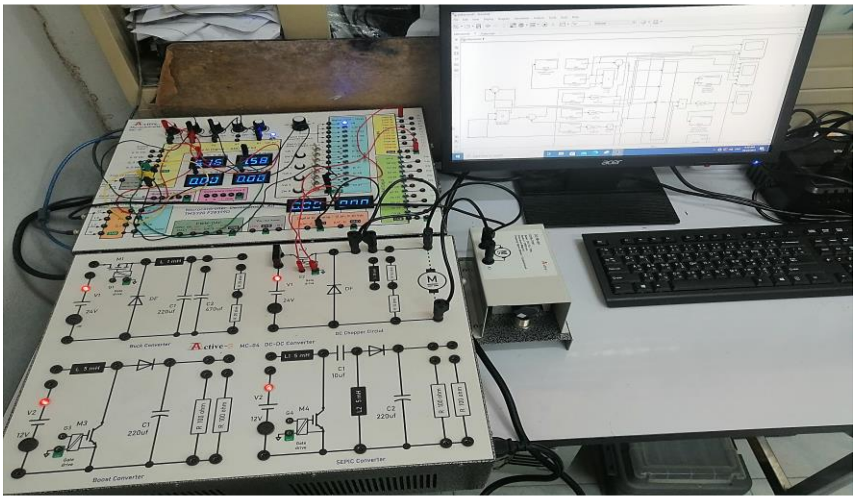


Figure 8. The experimental setup

The experimental model practice includes potentiometers, which allow modifying the system by modifying the gain of the system. This manual adjusts the parameters of the potentiometer, which has four different gain values (Kp, Ki, and Kd) as shown in Figure 9. Define input PID controller by using potentiometers: P1 is P-gain (0-10Vdc) convert to 0-4095 (12bit). P2 is I-Gain (0-10Vdc) convert to 0-4095(12bit), P3 is D-gain (0-1Vdc) convert to 0-4095(12bit). P5 is set point reference input, C2 is feedback path from speed sensor from 0-4000 rpm to 0-4095(12bit).

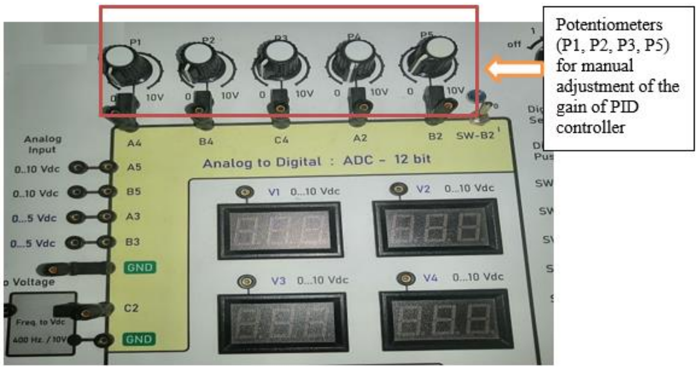


Figure 9. Experiment lab practice set

3.2. The proportional integral derivative controller with MATLAB/simulink program

The experiment model study in only PID control [27], [28] is shown in Figure 10. The PID controllers tune parameters using hand-tuning methods [29]. This PID controller combines proportional, integral, and derivative controls together. The controllers are connected in parallel. The gain values of K_P, K_I, and K_D depend on the condition of the error between the input value and the output value. When tuning these parameters, the dynamic reactivity of the system can be improved, eliminating steady-state errors, reducing overshoot, and increasing the stability of the controlled system. The block parameters of the PID (z) controller to use a discrete-time domain is shown in Figure 11.

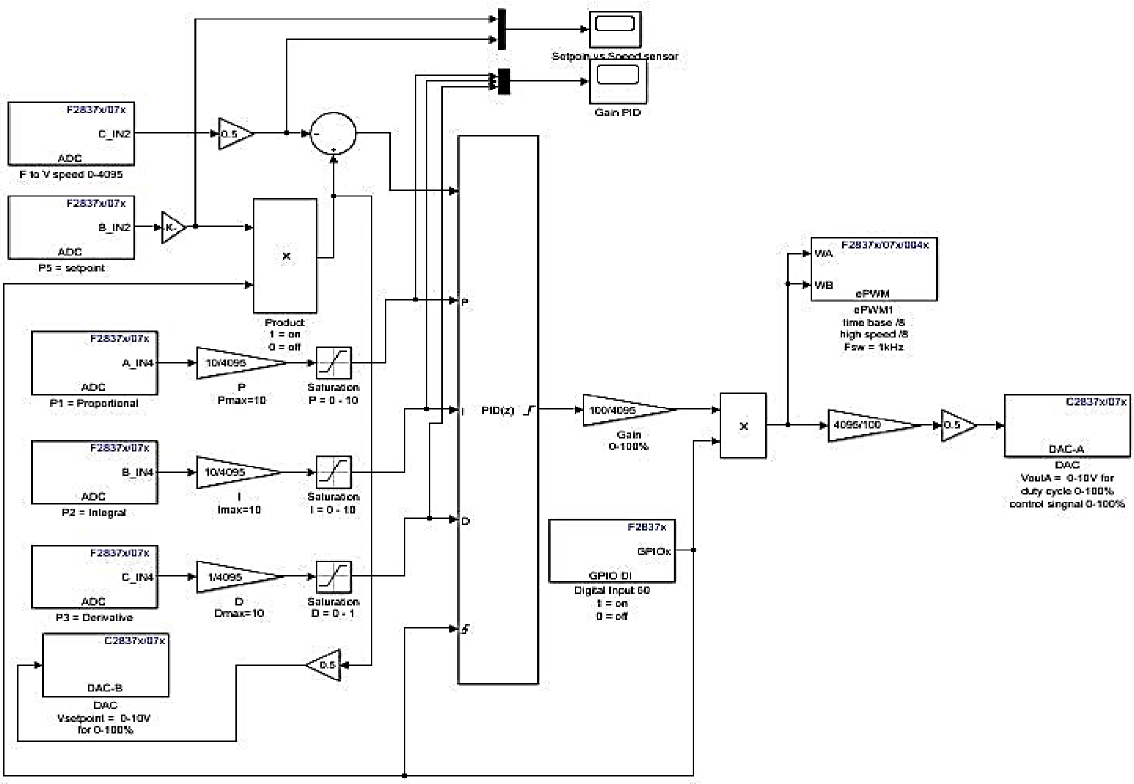


Figure 10. The MATLAB/Simulink block diagram in experimental setup

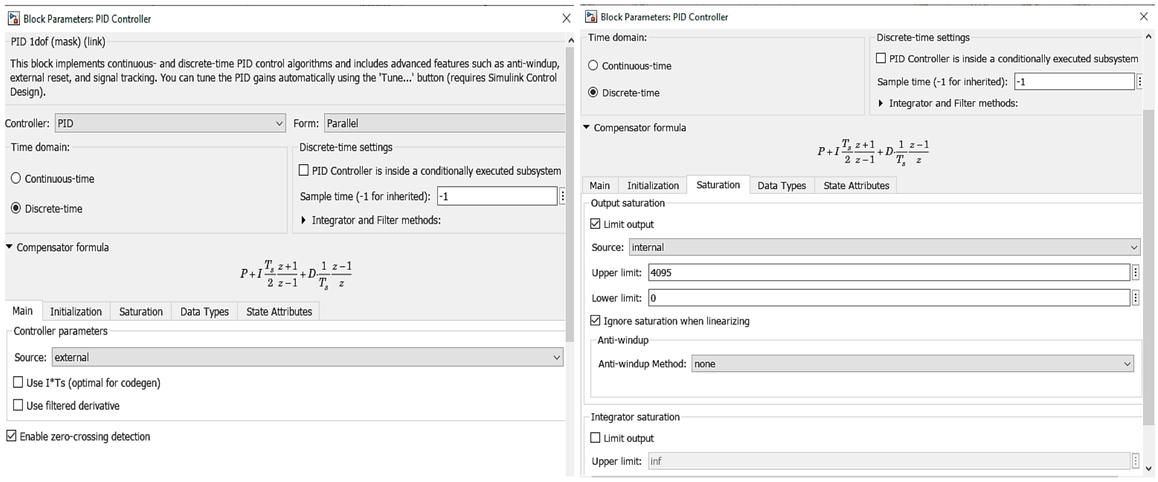


Figure 11. The block parameters PID controller in MATLAB/Simulink

3.3. Experiment of the fuzzy-based tuning PI-D controller

The working principle of fuzzy self-adjustment is that all error values are changed to adjust the parameters of the three PID controllers in real time. So that the system has good dynamic and static performance to desire response, minimize the settling time and rise time. The experimental cycle model in MATLAB/Simulink is shown in Figure 12.

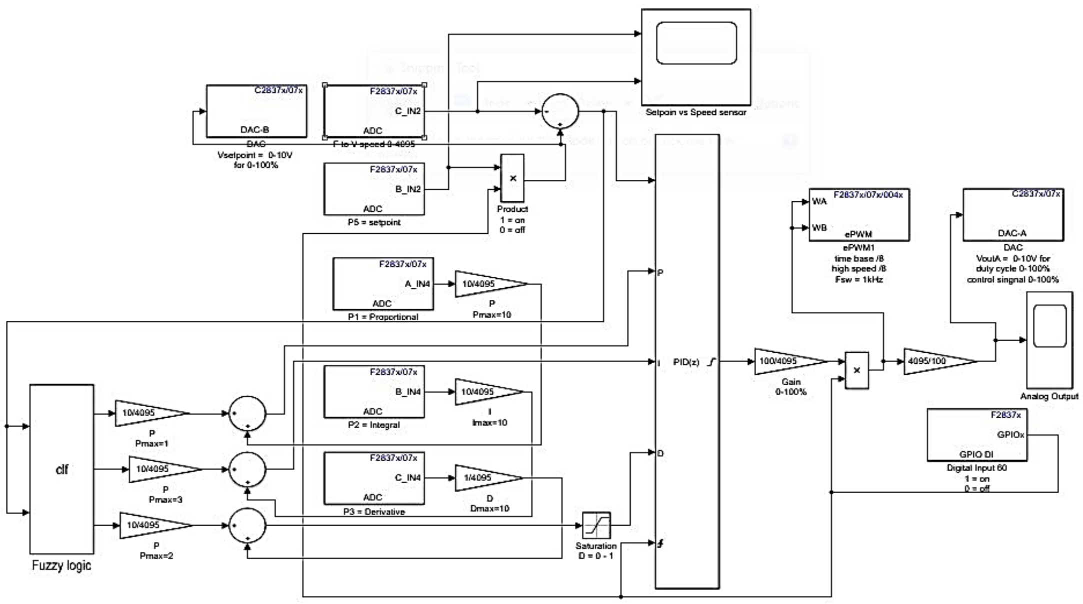


Figure 12. The experiment Simulink model of the fuzzy-based-tuning PI-D controller for PMDC motor

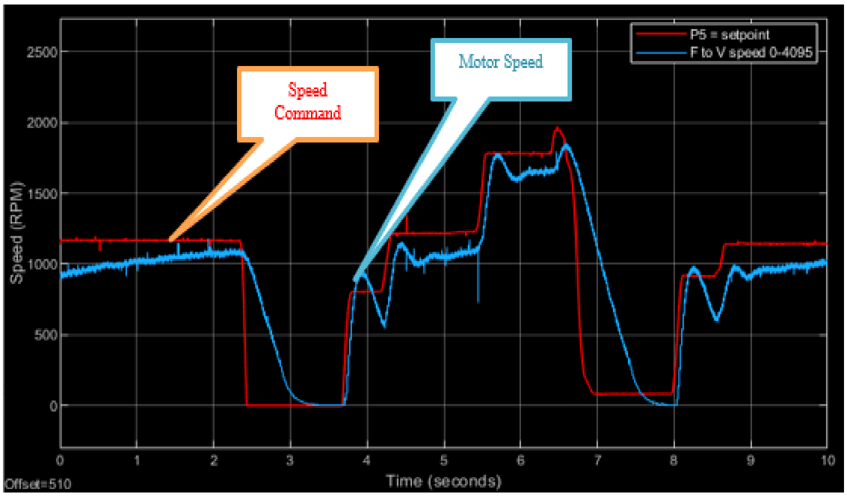
4. EXPERIMENT RESULTS AND DISCUSSION

The experimental results of both PID and fuzzy-based tuning PI-D controller were used to compare the advantages and disadvantages of speed control for the PMDC motor. The experiment is proposed to validate the correctness of the controller based on the model used to test that it has good motor speed control performance using both PID and fuzzy-based tuning PI-D controller schemes. The test results can be explained as follows.

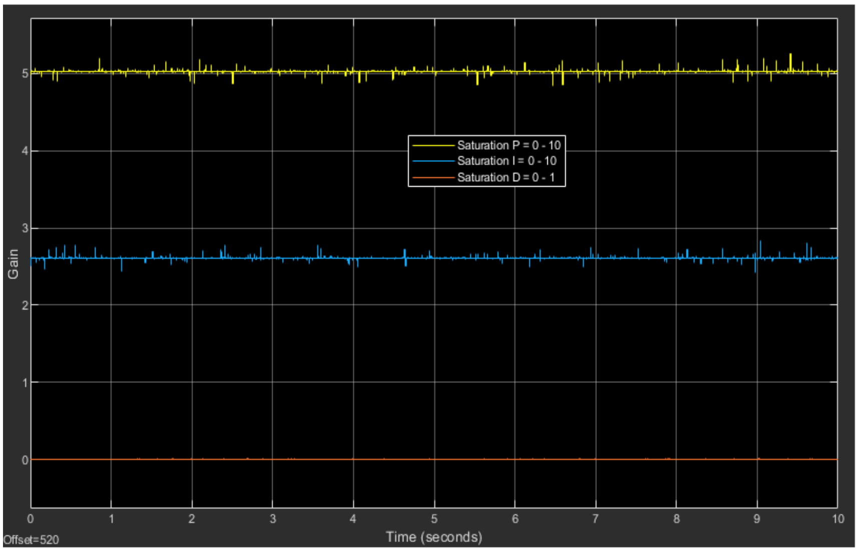
4.1. The results of PID controller for speed control of PMDC motor

The results of the experiment have been done using a PC with the Windows 10 operating system and MATLAB/Simulink R2018a. The test results of the motor speed control circuit with a PID controller are shown in Figure 10. It can be seen that while changing the input reference value, it takes a very long time for the velocity to reach the reference value, and in Figure 13, in the steady state, there is oscillation. The motor speed is unstable, and there is vibration.

Figure 13 shows test results from Figure 10 that have been performed, producing sudden changes in the PMDC motor. These tests have been performed by varying the potentiometer gains of $K_P = 5$, $K_I = 2.8$, $K_D = 0$, and set point gain (P5). It has not been saturated in any of the experimental cases. The steady-state errors of the dynamics system change with the same gain by the controller in Figure 13(b), Observe the steady-state response when using a PID controller. It will be found that the rotational speed of the motor is fluctuating and does not rotate smoothly, as shown in Figure 14. A better controller must be found to adjust this value. As will be presented in the next chapter.



(a)

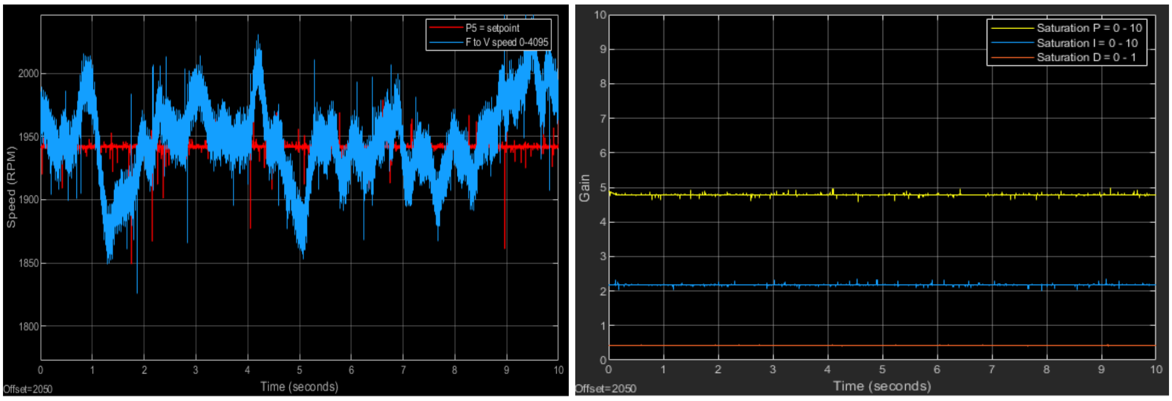


(b)

Figure 13. Experiment speed response of PMDC motor under difference speed reference input, (a) response of motor speed after use PID controller and (b) the output gain of PID controller

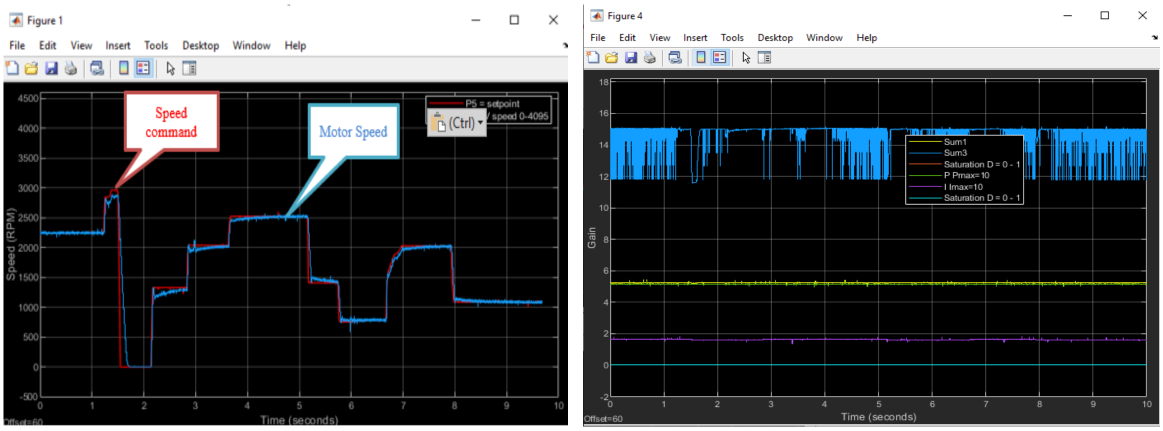
4.2. The results of fuzzy based tuning PI-D controller for speed control of PMDC motor

From the results of the experimental study, when connecting the circuit and using the frame diagram shown in Figure 12, the test results can be seen in Figure 15. The parameters of the fuzzy-based tuning PI-D controller adjustments are automatically adjusted to meet the desired response at various speed values. Therefore, it is found that the fuzzy-based tuning PI-D controller provides better system control performance than the conventional PID controller. When comparing the performance of the conventional PID controller with the customized fuzzy-based tuning PI-D controller, it was found that the fuzzy-based tuning PI-D controller provides better dynamic response. It has a shorter settling time, rise time, a steady state error of zero, an increasing maximum time exceeded, and a fairly strong anti-interference ability. When considering Figure 13 shows experiment speed response of PMDC motor under difference speed reference input. Figure 13(a) is response of motor speed after use PID Cotroller. Figure 13(b) is the output gain of PID controller. Figure 14 show the zoom out of experiment speed response of PMDC motor under steady-state response of speed reference input condition. Figure 14(a) is the steady state response of speed motor. Figure 14(b) is the gain of controller. Figure 15 shows experiment speed response of PMDC motor under difference speed reference input condition. Figure 15(a) is response of motor speed after use PID controller. Figure 15(b) is the output gain of fuzzy based tuning PI-D controller. When comparing the results of the motor speed responses of two types of controllers, it can be seen that the fuzzy-based tuning PI-D controller is able to control the system with more stability. There is less fluctuation in rotational speed or overshoot than with a PID controller, and reaching the set value or set point in a shorter time can be both positive and negative. In order to make the control system able to respond to external noise very well, this makes the control stability constant under various noises or disturbances. Table 3 summarizes the advantages and disadvantages of both controllers.



(a) (b)

Figure 14. The zoom out of experiment speed response of PMDC motor under steady-state response of speed reference input condition: (a) the steady state response of speed motor and (b) the gain of controller



(a) (b)

Figure 15. Experiment speed response of PMDC motor under difference speed reference input condition, (a) response of motor speed after use PID controller and (b) output gain of fuzzy based tuning PI-D controller

Table 3. The comparison between the conventional PID controller and the fuzzy based tuning PI-D controller

Parameter	PID Controller	The fuzzy based tuning PI-D controller
Overshoot	Present	Not present
Settling	More	Less
Transient	Present	Not present
Rise time	Less	More

5. CONCLUSION

Results of testing motor speed control using a chopper circuit, that has a TMS320F28379D microcontroller board as a generator for driving signals and measuring using the program Matlab\Simulink in real time to compare the controllers for controlling the speed of electric motors by using PID and the fuzzy-based tuning PI-D controller. From the test, it was found that the control performance of the two controllers would be compared. Both types of controllers are designed to have convergence times to steady state (setting time) at the same time. The fuzzy-based tuning PI-D controller provides slightly better steady-state error values. PID controllers must be adjusted to every control at the desired rpm, whereas fuzzy logic controllers require. It has a wider range of adjustments each time and has a better response than using fuzzy logic to adjust the parameters. The K_P, K_I, and K_D gains of the PID control system are control systems that adjust the response to changes between input and output data. The fuzzy-based tuning PI-D controller is an automatic system with a PID controller controlling the processing of results and a fuzzy controller adjusting the value. Parameters of PID Controller This system is a system that can adjust parameters automatically (self-tuned PID controller).

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