

Implementation of Fuzzy Logic System for DC Motor Speed Control using Microcontroller

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Abstract:-

This paper presents an insight into the speed control of DC motor using a fuzzy logic controller to meet the desired speed. Fuzzy logic is one of the most successful applications of fuzzy set in which the variables are linguistic rather than numeric. A fuzzy logic controller (FLC) is based on a set of control rules (fuzzy rules) among linguistic variables. The personal computer provides the necessary flexibility in setting any speed profile with the use of fuzzy packages. The proposed fuzzy controller results in a better response compared to the basic fuzzy controller and normal response of DC motor. It consists of two major parts; hardware implementation and software development. In the hardware part, H-bridge DC motor driver will be designed and developed. The designed H-bridge DC power converter will be used as the hardware interface between DC motor and the microprocessor-based fuzzy controller. A frequency to-voltage converter (FVC) and analogue-to-digital converter (ADC) will be used to convert and provide the actual speed signal from speed rotary tachometer, and to be used as fuzzy controller input. The software part aims to design and develop a digital fuzzy logic speed controller by varying the pulse width for DC motor applications using MATLAB/simulink. In summary, this paper hopes to demonstrate the capability of fuzzy logic in designing a controller for a DC motor. It also signifies the importance of the need for further research in the DC motor speed controller design.

Keywords: Converter circuit, DC motor drive, Fuzzy controller, Microcontroller, MATLAB/simulink.

I. Introduction:-

The development of high performance DC motor drives is very important in industrial as well as other purpose applications. The DC motors are used in various applications such as defence, industries, Robotics etc. DC drives, because of their simplicity, ease of application, reliability and favorable cost have long been a backbone of industrial applications. DC drives are less complex with a single power conversion from AC to DC. The DC drives are normally less expensive for most horsepower ratings.

DC motors have a long tradition of use as adjustable speed machines and a wide range of options have evolved for this purpose. In these applications, the motor should be precisely controlled to give the desired performance. Many varieties of control schemes such as proportional (P), proportional integral (PI), proportional derivative integral (PID), adaptive and fuzzy logic controller (FLCs) have been developed for speed control of DC motors [1]. The proposed controller system consists of multi-input fuzzy logic controller (FLC) for the speed control. The proposed system utilizes the fuzzy logic controller and AC to DC converter. The drive system has the characteristics of precise, fast, effective speed references tracking with minimum overshoot and minimal steady state error. The fuzzy logic speed command profile is followed even under load torque disturbances.

The proposed system shown in Figure 1 consists of AC-DC converter to drive the DC motor.

The encoder is used to sense the speed and to be used for speed feedback. A microcontroller is used to generate the PWM signal to switch the converter, during the implementation. The system consists of fuzzy speed control loop in which the actual speed is sensed by encoder and the error signal is obtained by comparing with the reference speed. From the present error and previous error the change in error is calculated. In the proposed system two input fuzzy controller is used. The error (e) and change in error (ce) are given as inputs to the fuzzy controller. The output of fuzzy controller is denoted as duty cycle. The change in duty cycle for the converter can be calculated from the new duty cycle and previous duty cycle. The input and output gain of the fuzzy controller can be estimated by simulation. The fuzzy controller can reduce the error to zero by changing the duty cycle of the switching signal.

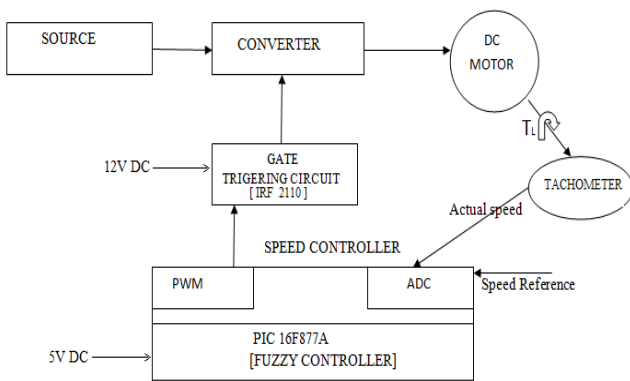


Figure 1: Proposed hardware system

The rest of the paper is organized as follows. Section 2 deals with the mathematical modeling of DC motor, section 3 deals with the open loop control of the DC drive, section 4 gives an insight into the fuzzy rule base for the speed control of the DC drive, section 5 explains the hardware development using an embedded system, section 6 gives the simulation and hardware results and section 7 gives the conclusion of the paper.

2. Mathematical Model of DC Motor

The simulation of the entire setup can be done using following DC motor Modeling equations.

$$\phi_m = K_f I_f = \text{constant}$$

$$T = K'_m \phi I_a$$

$$T = K'_m K_f I_f I_a$$

$$\omega_m = \frac{d\theta(t)}{dt}$$

$$e_a = E_b + I_a(R_a) + L_a \frac{di_a}{dt}$$

Applying Laplace transform and solving

$$\frac{\theta_m(s)}{E_a(s)} = \frac{G(s)}{1 + G(s)H(s)}$$

where

$$\tau_m = \frac{J_m}{B_m}$$

and

$$\tau_a = \frac{L_a}{R_a}$$

$$K_m = K'_m K_f$$

$$G(s) = \frac{K_m}{sR_a B_m (1 + s\tau_m)(1 + s\tau_a)}$$

$$H(s) = sK_b$$

where the motor parameters are

L_a Armature Inductance

J_m Inertia of the motor

K_b Back emf constant

B_m Coefficient of friction

R_a Armature Resistance

K_t Tachometer constant

K_T Torque constant

N Gear ratio

J_L load Inertia

B_L Load friction

T_D Disturbance torque

Figure 2: Modelling of DC motor

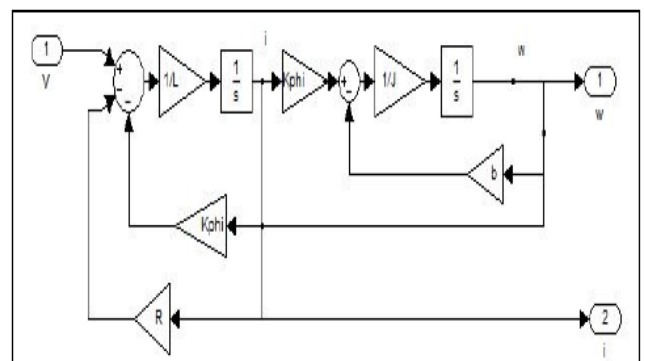
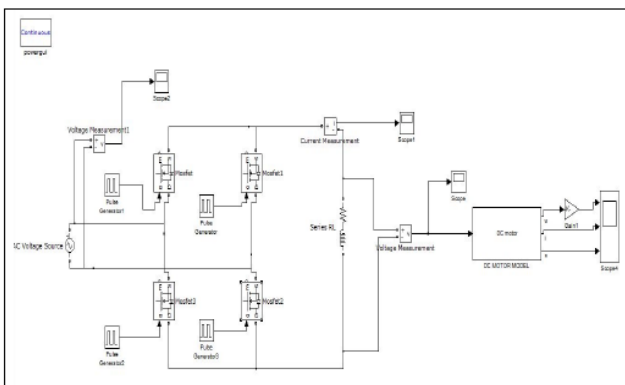


Table 1: Specifications to model DC motor

| DC motor Parameters | Value |
|---------------------------------|-----------------------|
| Motor rating | 3HP |
| Dc supply voltage | 220V |
| Motor rated Current | 4.3A |
| Armature resistance R_a | 0.6 Ω |
| Armature inductance L_a | 0.008 H |
| Inertia constant J | 0.011 Nm ² |
| Damping constant B | 0.004Nm/rad/s |
| Torque constant parameter K_t | 0.556 |
| Back emf constant K_b | 0.556 |
| Speed | 1800rpm |

Figure 3: Open loop simulation



3. Open loop and Closed Loop Control of a DC Drive

Figure 3 shows the open loop simulation in MATLAB. Converter switches has been given a fixed pulse width of firing pulse, whose output is given to a filter. The filtered output is given to DC motor whose speed is measured. The simulation circuit of the closed loop system shown in figure 4 consists of a converter designed using MOSFET power switches. The duty cycle of the triggering pulses given to the MOSFET switches is varied to vary the speed of the DC drive, which is the pulse width modulation control. The speed output is given to the fuzzy logic toolbox which is a fuzzy PI controller. The output speed is compared with a reference speed and the error signal is obtained. The fuzzy PI controller has two inputs, the error and the change in error.

4. Fuzzy Rule base for Speed Control of DC motor

The fuzzy controller block for a DC motor is shown in figure 5. The three principal elements to a fuzzy logic controller are

1. Fuzzification module (Fuzzifier)
2. Rule base and Inference engine
3. Defuzzification module (Defuzzifier)

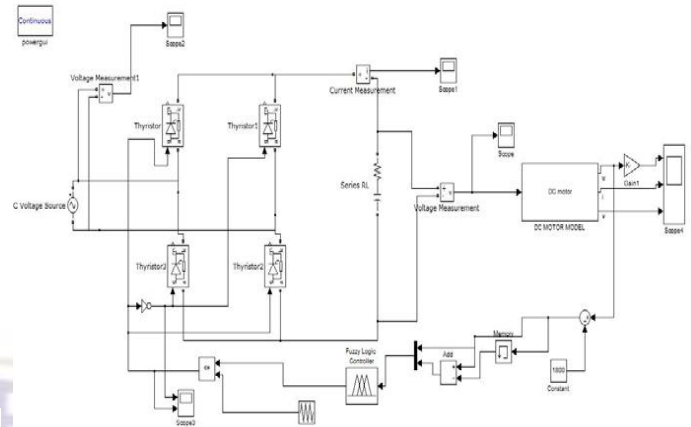


Figure 4: Closed loop simulation using fuzzy control

The fuzzification module assigns suitable linguistic values for the input data, this may be viewed as labels of fuzzy sets. The knowledge-base, consisting of input and output membership functions, along with the rule-base provides information for the appropriate fuzzification operations. In order to obtain the desired fuzzy control action, defuzzification is performed on the fuzzy input variables with the help of rulebase and inference mechanism. The rules commonly used are the IF, THEN rules. The inference mechanism is the kernel of fuzzy logic controller. The control rules are evaluated by an inference mechanism. Individual rule based inference (firing) is used here. The Mamdani algorithm is used for the implementation of the inference mechanism. Defuzzification is a technique of converting the final combined fuzzy conclusion into a crisp one. The defuzzified output is in turn applied to the plant.

The algorithm for fuzzy speed control in detail with a numerical example is included in each step for clarity of understanding the principle. The triangular membership functions for input variable speed error (e), change in speed error (ce) and control output (du) i.e. change in firing angle are shown in normalized units.

The general considerations in the design of the controller are:

- If both e and ce are zero, then maintain the present control setting i.e. $du=0$
- If e is not zero but is approaching this value at a satisfactory rate, then maintain the present control setting.
- If e is growing then change the control signal du depending on the magnitude and sign of e and ce to force e towards zero.

The linguistics variables are defined as fuzzy set. A membership function is a curve define, shows a value of a fuzzy variables in a certain region are mapped to a membership value μ (degree of membership) between 0 and 1. In order to reduce the

number of membership function the width of the membership is kept different.

There are three linguistic variables:

- Error(e)
- Change in Error(ce)
- Output(du)

4.1. Numerical Range of Linguistic Variable - Error (e)

The numerical range of values for error and the corresponding linguistic notation is shown in the table2. The error indicates the difference between the actual output speed and the reference speed. The values of the error are their scaled values.

Table 2: Linguistic variable range of error

| Linguistics Variable | Notation | Numerical Range |
|----------------------|----------|-----------------|
| Negative Minimum | NM | {-0.25,0.25} |
| Negative small | NS | {0,0.25,0.5} |
| Zero | Z | {0.25,0.5,0.75} |
| Positive small | PS | {0.5,0.75,1} |
| Positive Minimum | PM | {0.75,1,1.25} |

4.2. Numerical Range of Linguistic Variable - Change in Error (ce)

The numerical range of values for change in error and the corresponding linguistic notation is shown in the table3. The change in error indicates the differential of the error . The values of the change in error are their scaled values.

Table 3: Linguistic variable range of change in error

| Linguistics Variable | Notation | Numerical Range |
|----------------------|----------|-----------------|
| Negative Minimum | NM | {-3,-2,-1} |
| Negative small | NS | {-2,-1,0} |
| Zero | Z | {-1, 0, 1} |
| Positive small | PS | {0,1,2} |
| Positive Minimum | PM | {1,2,3} |

4.3. Fuzzy Rule Matrix

The control rules that relate the fuzzy output to the fuzzy inputs which are derived from general knowledge of the system behavior is shown in table 4. Some of the control rules are developed using trial and error method.

Table 4: Rule Matrix Table

| e \ ce | NM | NS | Z | PS | PM |
|--------|----|----|----|----|----|
| NM | NM | NM | NM | PS | Z |
| NS | NM | NM | NS | Z | PS |
| Z | NM | NS | Z | PS | PM |
| PS | NS | Z | PS | PM | PM |
| PM | Z | PS | PM | PM | PM |

To illustrate the control of motor by the fuzzy rule matrix, 4 valid rules from the rule matrix table are identified for Zero & Positive small of error and change in error.

These are,

1. IF e=Z AND ce=Z, THEN du=Z
2. IF e=Z AND ce= PS, THEN du=PS
3. IF e=PS AND ce=Z, THEN du=PS
4. IF e=PS AND ce=PS, THEN du=PM

The Calculations are detailed as below.

If the Reference speed is denoted as ω_r^* and Actual speed as ω_r , the error $e(k)$ and change in error $ce(k)$ are calculated, where

$$e(k) = \omega_r^* - \omega_r$$

$$ce(k) = e(k) - e(k-1)$$

$$e(pu) = e(k)/G_c$$

$$ce(pu) = ce(k)/G_c$$

From the figure 5 and 6,

$$e = 0.8,$$

$$ce = 0.55$$

Calculate the degree of membership of e and ce for the relevant fuzzy sets shown in figure 6 and figure 7.

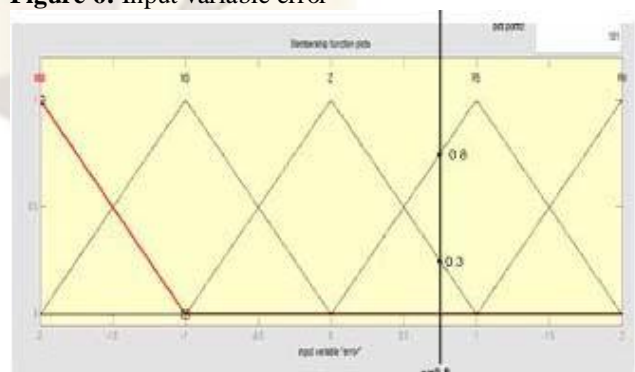
$$\text{From figure 6, } \mu_Z(e)=0.3 \text{ and } \mu_{PS}(e) =0.8$$

$$\text{From figure 7, } \mu_Z(ce)=0.7 \text{ and } \mu_{PS}(ce) =0.4$$

Retrieve the amount of correction du_i ($i=1, 2, 3, 4$) corresponding to each rule in the table

1. $Du_1=0$ for Z corresponding to $DOB_1=0.7$
2. $Du_2=0.35$ for PS corresponding to $DOB_2=0.3$
3. $Du_3=0.35$ for PS corresponding to $DOB_3=0.3$
4. $Du_4=0.6$ for PM corresponding to $DOB_4=0.8$

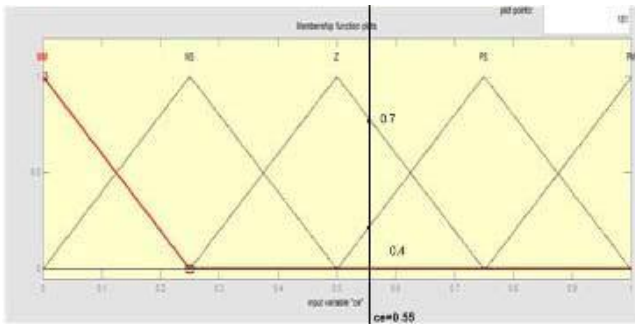
Figure 6: Input variable error



Calculate the DOB (degree of belongingness) of each rule using the AND or min operator

1. $DOB1 = \min \{ \mu z(e), \mu z(ce) \} = \min \{ 0.3, 0.7 \} = 0.3$
2. $DOB2 = \min \{ \mu z(e), \mu PS(ce) \} = \min \{ 0.3, 0.4 \} = 0.3$
3. $DOB3 = \min \{ \mu PS(e), \mu z(ce) \} = \min \{ 0.8, 0.7 \} = 0.7$
4. $DOB4 = \min \{ \mu PS(e), \mu PS(ce) \} = \min \{ 0.8, 0.4 \} = 0.4$

Figure 7: Input variable change in error



By calculating the crisp du by centroid - Defuzzification method we have
The calculated output value $du = 0.876$ as seen from the rule surface in figure 9. The membership function of output is shown in figure 8.

Figure 8: Output variable

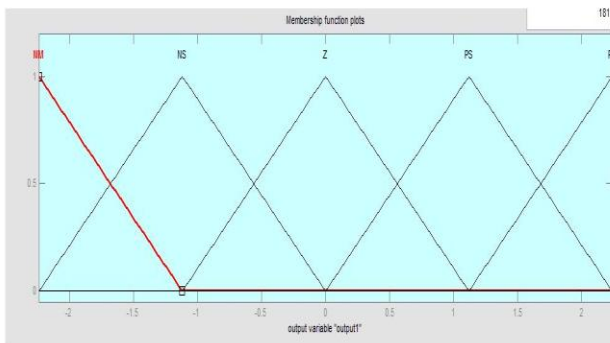
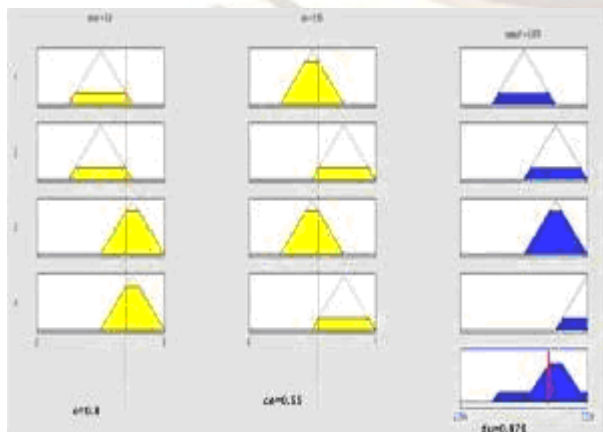


Figure 9: Rule Surface



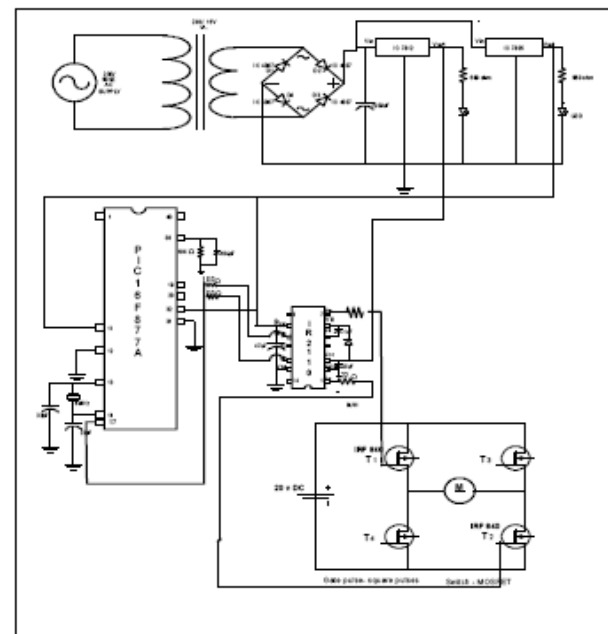
Hardware Development for Fuzzy Logic based DC Motor Control using Embedded System

This section deals with hardware development of dc motor control involving fuzzy implementation. It consists of rectifier circuit, power supply unit circuit, control circuit and driver circuit. In control circuit, the driving pulses required for MOSFET's are obtained from PIC 16F877A microcontroller. The overall hardware circuit is shown in figure 10

5.1. Control Circuit Design

The microcontroller external circuit is shown in Fig 6.4 Port C is taken as output port. In that RC2 are used to generate gate pulse for MOSFET Q1 and Q2. Based on the data given in the data sheet of PIC Microcontroller we need to give 5V supply to the pin 11 and 32. We also need to ground the pin 12 and 31. The 16MHz crystal oscillator is used to generate clock pulse to the microcontroller. It is connected between the pin 13 and 14. Also capacitors (33 μ F) are connected to the pins 13 and 14. 4 KHz is the switching frequency of semiconductor switch.

Figure 10: Overall Hardware Circuit



5.2. Implementation of Speed Control of DC Motor using Fuzzy Logic

The snapshot of the hardware circuit and their necessary waveforms of converter circuit are shown in Figure 16. The rectified 12V DC supply is given to 7812 and 7805 voltage regulator to obtain a constant 12V and 5V DC supply. This supply is given to driver circuit and microcontroller for its operation. The pulse from microcontroller is given to drive the controller converter switches to control DC motor. PMI Servo disc DC motor with Tachometer is

connected to the PIC microcontroller .The voltage pulse to trigger the MOSFET's with a switching frequency of 4KHZ shown in figure 11.

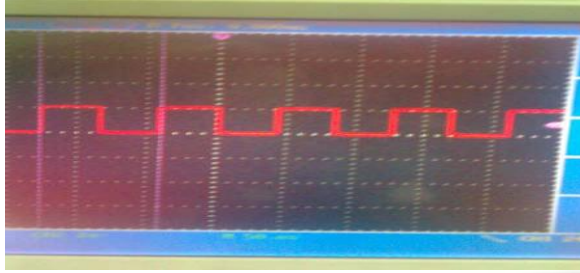
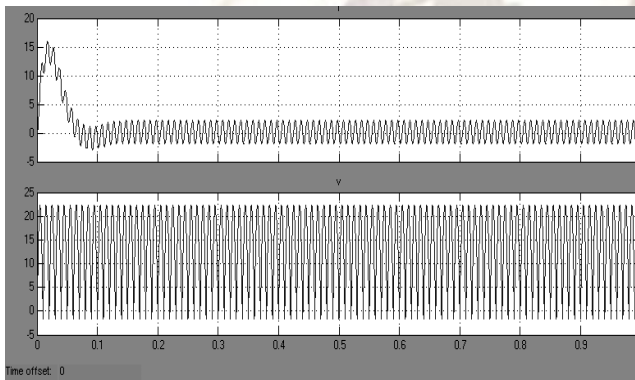


Figure 11: Switching pulses to trigger the MOSFET

6. Simulation and Hardware Results

The output voltage and current waveforms for the open loop control and fuzzy control are shown in figure 12

Figure 12: Output current and voltage wave forms



The snapshot of real time implementation of speed control of DC motor using PIC microcontroller and respective output voltage of tachometer is shown.

The output speed for open loop and fuzzy control are shown in figure 13, and the snap shot of the implemented hardware circuit is shown in figure 14.

Figure 13: Output speed for open loop and fuzzy control

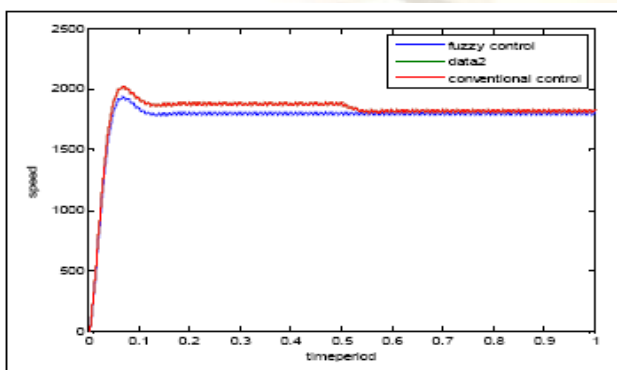


Figure 14: Hardware implementation



7. Conclusion

Recent developments in science and technology provide a wide range scope of applications of high performance DC motor drives in area such as rolling mills, chemical process, electric trains, robotic manipulators and the home electric appliances.They require speed controllers to perform tasks. Hence, a fuzzy based DC motor speed control system was designed using PIC microcontroller. It is a closedloop real time control system, which maintains the desired speed even when there is a variation of load. In this paper, a comprehensive analysis of DC drive system has been performed by using fuzzy logic controller. The simulation model is implemented in MATLAB/simulink environment. From the output speed wave form , we can see that the speed becomes constant at 0.6 sec for an open loop system while it becomes constant at 0.1 sec for a fuzzy PI . Also in Fuzzy PI we have a smooth speed control with less overshoot and no oscillations. In the hardware part, the fuzzy logic control algorithm was developed using Mikro C, a high level programming language for programming a PIC microcontroller. The C-structure programming overwhelm the difficulties may encountered if programming the microcontroller using Embedded C language. The fuzzy logic algorithm programmed will be compiled into the memory system .As the result, the fuzzy controller developed is able to provide precise PWM signal in order to drive the DC driver. Then, the PIC microcontroller is interfaced between the DC motor and DC speed drive to run in real time and debug.

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