Fuzzy algorithm implementation in microcontroller for DC motor control

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Abstract

In industrial automation, motor control technique plays the vital role. Motor consists of inductor or electromagnet. Causing inductor or electromagnet, magnetic inductions are produces which resists any change of motor speed. Hence, according to set point, precise speed control is challenging. However, using various control technique can be controls the speed of DC motor. The aim of the present paper is to implement hardware and control the speed of DC motor using embedded fuzzy logic. Set point have been applied externally and recorded the speed of motor through opto-isolator sensor module. In the hardware of DC motor control keypad, 2x16 LCD, DC motor driver and opto-isolator module are interfaced to PIC microcontroller. The Fuzzy algorithm is embedded in the microcontroller wherein input fuzification signals 'error (Δe)' and 'change in error (e(n))' and output fuzification signal 'PWM'. The both of inputs of fuzzy algorithm are varied and record output of fuzzy algorithm which is PWM. Moreover, the hardware implementation has been tested for real time control of DC Motor.

Keywords: Fuzzy algorithm, Speed control, PIC microcontroller, Hardware implementation

1. Introduction

DC motor is designed to convert direct current electrical energy to mechanical energy which works on the principle of electromagnetism. According to the applications of DC motors, it is available in different types, dimensions and sizes. As small motors can be used for toys, tools and home appliances while larger one can be used for elevator, vehicle and industries. DC motor driving system is an indispensable part of industrial applications like actuation and robotics, where speed control is required. DC motors are preferred for various control systems, due to their potential ability in applications involving high torque, speed and position control. In wide variety of applications of DC motor, we have to control the speed of motor. Because of inductive and magnetic effects of motor, its control is critical. For precision control of DC motor is the challenging for researcher. As compared conventional controllers, Fuzzy controller provides smooth output (Goel et al., 2012). For controlling of DC motor, different controllers can be used however here the embedded fuzzy control have been used.

The characteristics of DC motor pertaining to the performance and efficiency are suitable for many speed and position control systems (Meha *et al.*, 2011). Pulse Width Modulation (PWM) is a technique used for switching a device (MOSFET) with reference to analog signal. DC motor speed control system is a complex nonlinear control system, because of the various parameters influence each other (Nanda and Crow, 1995). Fuzzy logic approach is to make decisions based on 'degrees of truth' rather than

the modern computer, which is based on usual '0 or 1' Boolean logic. Fuzzy logic seems closer to the way our brain works (Zadeh, 1965). Fuzzy logic is followed by three steps: fuzzification, fuzzy inference and defuzzification. Average Weighted Defuzzification (AWD) method finds the resultant PWM count. Harb and Smadi (2009) have reported the performance improvement in dc motor using fuzzy logic controller. Yan *et al.* (2012) have designed PID and fuzzy PID controller in MATLAB for DC motor speed control application. They have studied the performance of PID and fuzzy-PID controllers. Ramadan *et al.* (2014) have proposed a FPGA based DC fuzzy logic motor control. (Pravadalioglu, 2005) has designed the Simulink model of PI and fuzzy model in MATLAB and studied the performance of dc motor. Lim (1995) has implemented the fuzzy PID controller and examined the real-time experimental study of DC motor. Hanamane *et. al.* (2006) proposed the temperature control using microprocessor. He has provided the set point temperature and studied the performance of heater using fuzzy logic.

In the present paper, the Mamdani's Inference method is employed for controlling the DC motor speed. The embedded 'C' code is written for Programmable Interface Controller (PIC) 16F877A wherein two inputs one output fuzzy logic controller (FLC) with Mamdani's Inference method. In Embedded 'C' code input parameter 'error' and 'change in error' is calculated which help to increasing the degree of accuracy. However for fuzzy logic the degrees of truth: ω_1, ω_2, ω_3 and ω_4 are finds then it is used for computation of PWM. The generated PWM is applied to FET for driving of DC motor. The opto-isolator sensor module is used to measure the RPM of DC motor. The measured RPM is provided to PIC microcontroller as an input.

2. Block Diagram DC Motor Control System

The output of opto-isolator sensor module is present speed of motor while the output of keypad is set point value. Present speed (R) of the DC motor and set point (S) are applied to the ADC channels A_1 and A_2 of PIC microcontroller. 'Error $(e_{(n)})$' is the difference between present speed (R) and set point (S). According to 'previous error' (Stored error $e_{(n-1)}$) and 'error $(e_{(n)})$', finds the 'change in error (Δe)'. The fuzzy algorithm is developed for two inputs ($e_{(n)}$ and Δe) and one output (PWM count) system which is embedded in microcontroller in the form of code. When change in input occurs the fuzzy logic algorithm generates appropriate PWM count in the microcontroller. The generated counts are stored in corresponding resistor (CCPR1L) of microcontroller which is used for motor driver FET to control the speed of DC motor as shown in Figure 1.
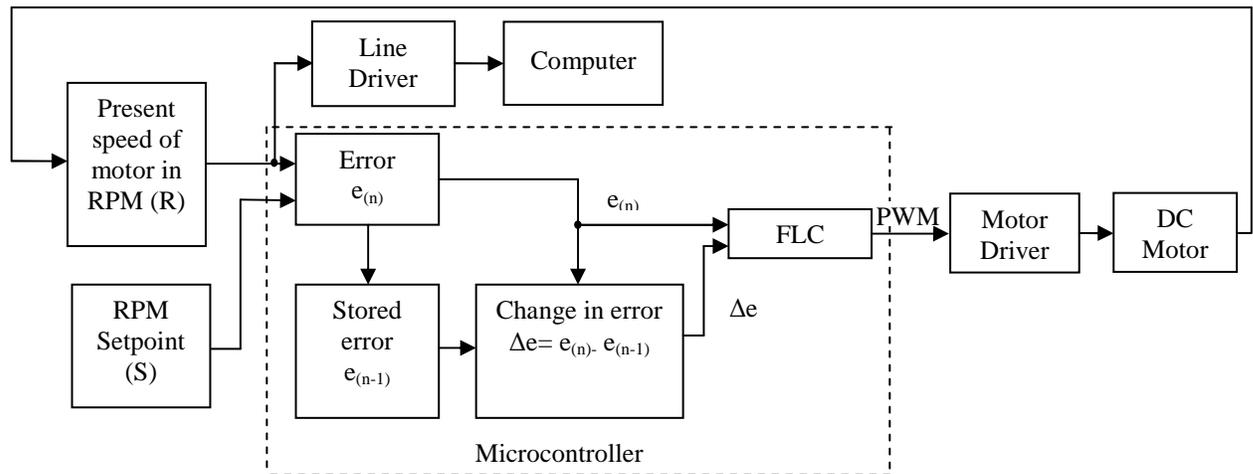

Figure 1. Block diagram of fuzzy based DC motor control system

3. Circuit Diagram Explanation of DC Motor Control System

A 5-volt power supply is constructed for source voltage of control system. The three reset keys are interfaced to PIC 16F877A microcontroller. Out of these one key is used for resetting the circuit and other two keys are used for making of set point while it is operating as an increment and decrement logic. The OS25B10 sensor is a high performance photo interrupter consisting of light emitting diode and high sensitive phototransistor. Utilization of this sensor is for measurement of fan speed while it is considered as one input. The generated PWM through microcontroller is applied to the gate of the MOSFET IRF540 for switching. FET is works like a driver. The DC motor connected between Vcc and drain of the MOSFET and source terminal of MOSFET is connected to ground however, PWM is applied to gate of MOSFET as shown in Figure 2. In this type of circuit connection the motor speed is depends on PWM which is applied to the gate of driver. The LCD 2x16 is interfaced to microcontroller for displaying of set point, and present motor speed. The set point, PWM and present motor speed is also send to computer through max 232 for further reference.
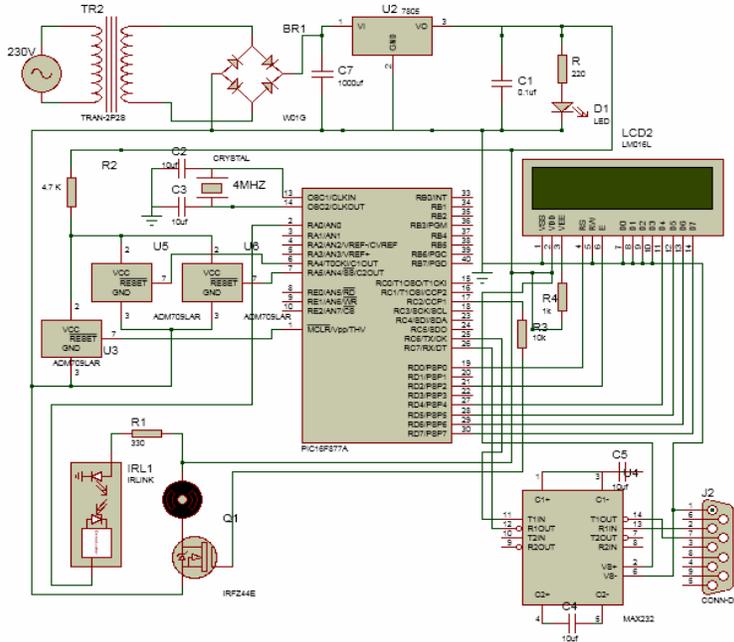
Figure 2. Circuit diagram of embedded fuzzy DC motor control

4. Fuzzy Variables

The three variables are given to fuzzy algorithm viz. 'error' and 'change in error' as input and 'PWM' as an output. These variables and their equation with partitions are shown in Table 1.

Table 1. Fuzzy Variables

Variable Name	Input / Output	Universe of Discourse	Membership Function		Range
Error ($e_{(n)}$)	Input	$0 \leq e_{(n)} \leq 1000$,	$\mu_{(e_{(n)})} = \dfrac{e_{(n)} - 500}{500}$	if	$0 \leq e_{(n)} \leq 500$
			$\mu_{(e_{(n)})} = \dfrac{1000 - e_{(n)}}{1000}$	if	$500 \leq e_{(n)} \leq 1000$
Change in error (Δe)	Input	$0 \leq \Delta e \leq 10$	$\mu_{(\Delta e)} = \dfrac{\Delta e - 5}{5}$	if	$0 \leq \Delta e \leq 5$
			$\mu_{(\Delta e)} = \dfrac{10 - \Delta e}{5}$	if	$5 \leq \Delta e \leq 10$
PWM Count (pwm)	Output	$0 \leq pwm \leq 6$	$\mu_{(pwm)} = \dfrac{pwm - 62}{62}$	if	$0 \leq pwm \leq 62$
			$\mu_{(pwm)} = \dfrac{125 - pwm}{63}$	if	$62 \leq pwm \leq 125$
			$\mu_{(pwm)} = \dfrac{pwm - 187}{62}$	if	$125 \leq pwm \leq 187$
			$\mu_{(pwm)} = \dfrac{255 - pwm}{63}$	if	$187 \leq pwm \leq 255$

4.1 Fuzzification of signals 'error ($e_{(n)}$)', 'change in error (Δe)' and 'PWM':
Fuzzification is the process of changing a real scalar value into a fuzzy degree of membership. This is achieved by the triangular membership function. The triangular membership function is the simple and easy for fuzzy algorithm. The 'error' signal range is 0-1000, partitioned into two triangular membership function entitled as Low and High. ω_1 and ω_2 are the degrees of membership

function as shown in Figure 3. The fuzzification of 'change in error' signal is similar to 'error' signal except range and labels as shown in Figure 4.
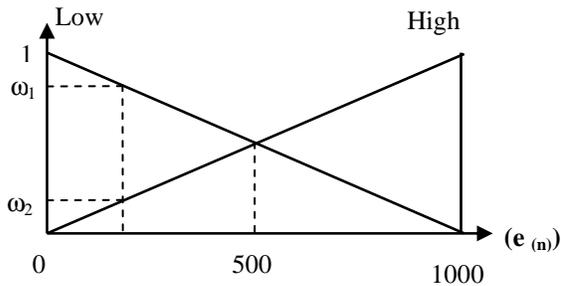
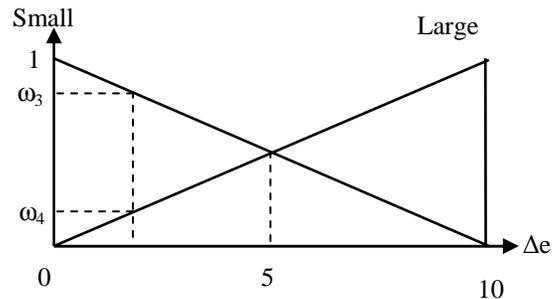Figure 3. Fuzzification of 'error ($e_{(n)}$)' signal

Figure 4. Fuzzification 'change in error (Δe)' signal

4.2 Fuzzification PWM count signal:

The PWM fuzzification signal is partitioned into four regions entitled as Increase, Mentain-1, Mentain-2 and Decrease. The range of fuzzification of binary counts signal is from 0 to 255, which is shown in figure 5.
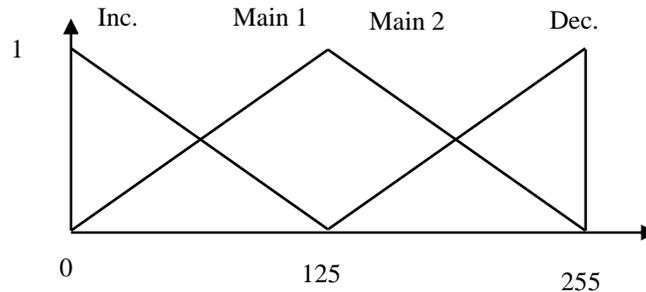
Figure 5. Fuzzification of binary count signal

The PWM count is divided into four triangular shaped membership functions. Labels and ranges of the membership functions are shown in table 2.

Table 2. Name and range of output membership function

Obs. no.	Name of the output membership function	Range of output membership function in binary count
1	Dec	0-63
2	Main-1	63-126
3	Main-2	126-192
4	Inc	192-255

4.3 Fuzzy Inference System:

Mamdani's fuzzy inference method is simple hence, it is commonly used in fuzzy methodology. It is combining fuzzified inputs according to the fuzzy rules to establish a rule strength. Finding the consequence of the rule by combining the rule strength and the output membership function and combining the consequences to get an output distribution completes the fuzzy inference process. Fuzzy Inference system is rule based system which comprising the IF-THEN format. The motor drive control knowledge is structured in form of fuzzy IF-THEN rules as shown in table 3. With reference to input signals, 'error' and 'change in error' the PWM count fuzzy logically inferred.

Table 3. Fuzzy rules

CIe (Δe) Error (e(n))	Small	Large
Low	Maintain-2	Increase
High	Decrease	Maintain-1

5. Fuzzy Code Implementation

The advanced electronics technology offers wide spectrum of target microcontrollers for embedding the fuzzy logic control routines. PIC microcontroller has 10-bit ADC with 4.882mV resolution which has 5V supply voltage. Notice that the ADC varies each step after variation of 4.882mV, hence maximum count of ADC is 1024. Causing we have selects the range of input fuzzification signal 'error (e(n))' is 0 to 1000. The possible range of 'change in error' is less therefore has selects the range of input fuzzification signal change in 'error (Δe)' is 0 to 10. After generation of PWM it is stored into CCPR1L register of PIC microcontroller which is 8-bit hence selects the range of output fuzzification signal PWM is 0 to 255. During making of C- code, for 'error' signal the defined integer is x and for 'change in error' signal the defined integer is y. Similarly, for PWM the defined integer is V. W1 and W2, are the degrees of membership for 'error' signal and W3, and W4 are the degrees of membership for change in 'error' signal. 'A' is the defuzzified value that determines the PWM of PIC microcontroller. According to the first fuzzy inference rule (IF 'error' is low and 'change in error' is small THEN PWM is maintain-2), when the value of x is between 0 to 500 (x>=0 && x<=500) and the value of y is between 0 to 5 (y>=0 && y<=5) then gets the value of PWM using formula v =((126*w2)+(192*w1))/(w1+w2). The code of the fuzzy algorithm wherein four rules are written as is shown in figure 6.

```
if(x>=0 && x<=500)
            {
            w1=1000*(x-0)/500;
            w2=1000*(500-x)/500;
             v=((126*w2)+(192*w1))/(w1+w2);
     if(y>=0 && y<=5)
                 {
                 w3=10*(y-0)/5;
                 w4=10*(5-y)/5;
                 v1=((126*w4)+(192*w3))/(w3+w4);
                 }
      elseif(y>=5 && y<=10)
                 {
                 w3=10*(y-5)/5;
                  w4=10*(10-y)/5;
                 v1=((0*w4)+(163*w3))/(w3+w4);
                 }
            }
  else if(x>=500 && x<=1000)
            {
            w1=1000*(x-500)/500;
            w2=1000*(1000-x)/500;
             v=((192*w2)+(255*w1))/(w1+w2);
     if(y>=0 && y<=5)
                 {
                 w3=10*(y-0)/5;
                 w4=10*(5-y)/5;
                 v1=((192*w4)+(255*w3))/(w3+w4);
                 }
      elseif(y>=5 && y<=10)
                 {
                 w3=10*(y-5)/5;
                  w4=10*(10-y)/5;
                 v1=((63*w4)+(126*w3))/(w3+w4);
                 }
            }
      if(v>v1)
            {
            A=v;
            }
  else
            A=v1;
```

Figure 6. Embedded C-code listing

In program flow of fuzzy based DC motor control, initially have to select the value of data direction register then initialize the LCD and ADC. The inputs ADC signal and set point signal are calibrated. After calibration, calculate the 'error (x)' between set point RPM (S) and current RPM (R) of DC motor. This 'error' signal is applied to fuzzy algorithm as well as same 'error' signal is stored in register as 'stored error (z)'. 'Change in error (y)' is the difference between 'stored error (x1)' and 'error (x)' which is applied to fuzzy algorithm also. Obtained PWM using fuzzy inference rule is applied to gate of MOSFET as well as LCD for display as shown in Figure 7.

```
                    ┌──────────────┐
                    │    START     │
                    └──────┬───────┘
                           │
       ┌───────────────────────────────────────┐
       │  Initialize the data direction register │
       │        TRISA =FF, TRISD=00             │
       └───────────────────┬───────────────────┘
       ┌───────────────────────────────────────┐
       │   Initialize ADC LCD through commands  │
       └───────────────────┬───────────────────┘
       ┌───────────────────────────────────────┐
       │      Initialize Port A as sensor input │
       └───────────────────┬───────────────────┘
                           │ ◄────────────────┐
       ┌───────────────────────────────────────┐  │
       │ Calibrate the sensor signal and Calculate speed │
       └───────────────────┬───────────────────┘  │
       ┌───────────────────────────────────────┐  │
       │ Calculate the present error and change in error │
       └───────────────────┬───────────────────┘  │
       ┌───────────────────────────────────────┐  │
       │  Implement fuzzy rules and find the PWM count │
       └───────────────────┬───────────────────┘  │
       ┌───────────────────────────────────────┐  │
       │   PWM count is put into CCPR1L registor │
       └───────────────────┬───────────────────┘  │
       ┌───────────────────────────────────────┐  │
       │     Displays the present RPM into LCD   │
       └───────────────────┬───────────────────┘  │
                           └───────────────────┘
```
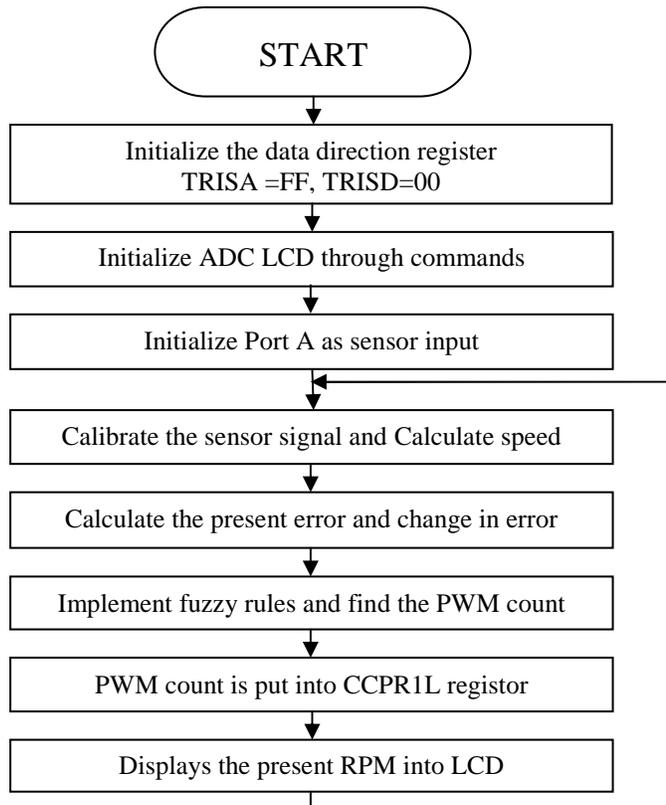
Figure 7. Program flow of DC motor control

The fuzzy algorithm based code is embedded into PIC 16f877A microcontroller and then this IC is used in circuit. The opto-isolator sensor module, motor driver FET, max 232 and 2x16 LCD are interfaced to PIC microcontroller. The hardware implementation photo snap is shown in figure 8.
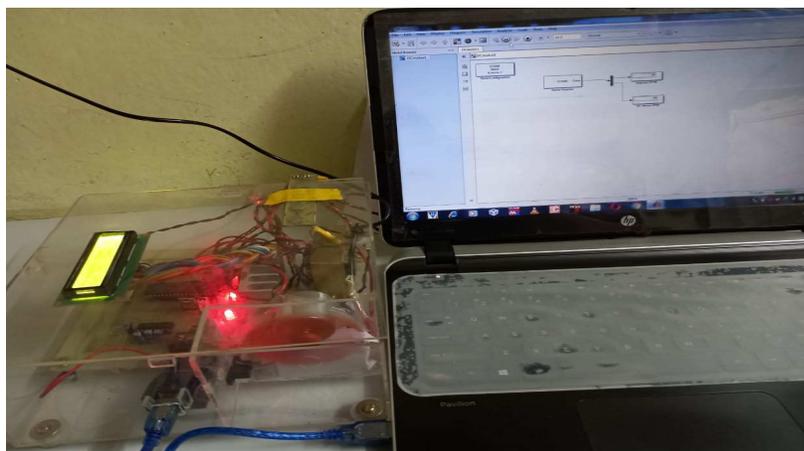

Figure 8. Hardware implementation image

6. Result and Discussion

The set point RPM have been applied to microcontroller through keypad and RPM of DC motor has measured through opto-isolator sensor module. The microcontroller finds the difference between set point RPM and DC motor RPM which is first input of fuzzy algorithm. The microcontroller also finds the difference between current error and previous error entitled as 'change in error' while it have applied to fuzzy algorithm as second input. The fuzzy algorithm is embedded in PIC 16F877A microcontroller wherein two input fuzzification signals 'error ($e_{(n)}$)' and 'change in error (Δe)' and one output fuzzification signal PWM. The varied 'error' signal and 'change in error' signal with obtained outputs are shown in Table 4. The one input fuzzification signal 'error' has been increases and another input fuzzification signal 'change in error' has varied randomly and then recorded the count of PWM. If input fuzzification signals 'error' and 'change in error' tries to increase or decrease then fuzzy algorithm controls the PWM and maintains the speed of DC motor which is equivalent to set point.

Table 4. The input and output fuzzification signals

Sr. No.	Input fuzzification signal (Error ($e_{(n)}$))	Input fuzzification signal (Change in error (Δe))	Output fuzzification signal (PWM)	Motor Speed (RPM)
1.	2	0.1	162	810
2.	6	1.5	163	812
3.	10	0.15	161	805
4.	19	0.4	160	797
5.	52	0.5	157	781
6.	100	0.8	152	762
7.	302	0.3	133	665
8.	500	1.0	117	587
9.	700	6	112	560
10.	800	9	104	518
11.	900	3.3	122	612
12	1000	9	57	283

The 'error' and 'change in error' signal is applied to fuzzy algorithm and obtains the appropriate PWM. This obtained PWM is applied to motor driver and recorded the speed of DC motor. Figure 9 shows the plot between motor RPM and output of fuzzy algorithm PWM. The PWM and RPMs are directly proportional to each other because Speed of DC motor is depends on PWM.
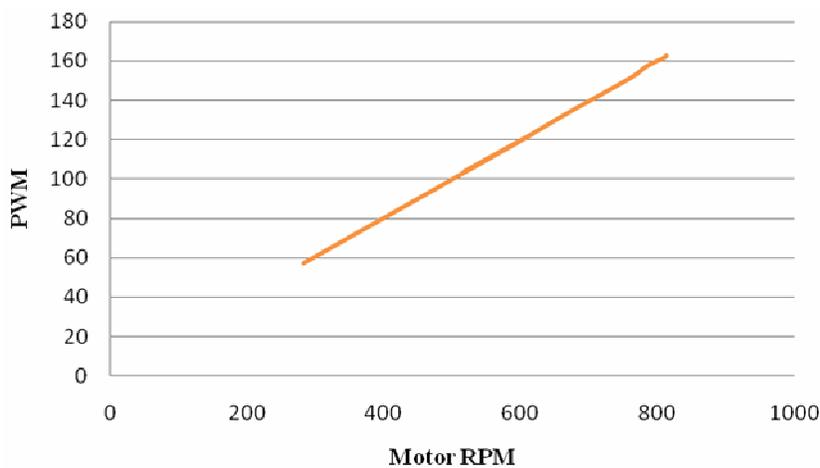

Figure 9. Graph between DC motor RPM and PWM

The microcontroller has been programmed for fuzzy PWM generation based on the set point RPM and measured RPM signals. The speed of DC motor has depends on variation of current flowing through it. In conformity with PWM, the motor driver controls the current flowing through in motor. With reference to RPM set point the embedded fuzzy algorithm generates appropriate PWM, consequently controls the speed of DC motor. RPM set point 450 have been applied to microcontroller which is depicted as blue

color line and recorded the motor rotations per minute as shown in figure 10. Causing inductive and magnetic effect of DC motor, the observed RPMs are slightly fluctuated, but approximately equal to the set point. However, it is vicinity of set point as shown in brown color line. The fuzzy algorithm based on microcontroller provided the speed control of dc motor in linear fashion. Fuzzy logic control system is applied to DC motor control application and achieves appropriate RPM of motor because fuzzy logic is operated on the basis human thinking.
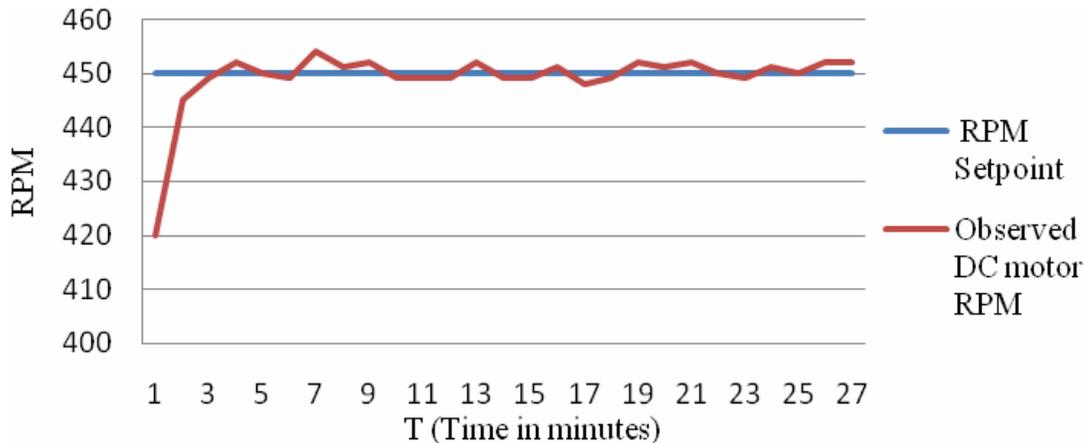

Figure 10. Graph between DC motor RPM and Time

7. Conclusion

In DC motor control system, according to set point it is very difficult to achieve the speed of DC motor because magnetic induction of motor. We know that the microcontroller is operated on program logic which provides precise output. In this paper, set points have been provided to microcontroller and achieved the appropriate speed of motor. The fuzzy algorithm is embedded in microcontroller wherein two inputs 'error' and 'change in error' while one output 'PWM'. The newly involved parameter is 'change in error' Due to inputs 'error' and 'change in error, increases the degree of accuracy of fuzzy algorithm hence the obtained motor speeds are more equivalent to set points. If fuzzy algorithm is embedded in the microcontroller, it could be a cost effective solution for industrial process control. If fuzzy-PID and fuzzy type-2 controller are embedded in microcontroller then can be improve the response of motor.

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