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Dual DC Motor Speed Control Based on Two Independent Digital PWM Signals using PIC16F877A Microcontroller

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Abstract

In this paper a dual open loop speed control system based on two independent PWM signals of small permanent magnet DC (PMDC) motors using PIC16F877A microcontroller (MCU) has been designed and implemented. The Capture/Compare/PWM (CCP) modules of the MCU are configured as PWM mode and the MCU is programmed using flowcode software package to generate two PWM signals with various duty cycles at the same frequency. A dual H-bridge channel chip SN754410 is used to drive the motors. The variation of PWM duty cycles is related directly to controlling the DC motors terminal voltage which directly proportional with speed of each motor. The complete PWM control system model has been simulated using proteus design suite software package. The development of hardware and software of the dual DC motor speed control system has been explained and clarified.

Keywords*: PIC16F877A, PWM, CCP1, CCP2, and PMDC*

1. Introduction

Direct current (DC) motors plays an effective role and still found in several industrial applications such as toys, disk drives, steel rolling mills, paper machines and in conjunction with power electronic devices [1]. The DC motors has many good characteristics in addition, high reliability, flexibility which make its speed control is very simple and suit different operating conditions. It converts electrical power into mechanical power through mutual effect between two magnet fields. One of these two magnet fields is often produced by permanent magnet in stator element [2]. The other magnetic field is produced by electric current passing through the rotor (armature) winding. This mutual interaction between the two fields produces torque leads to the rotor rotation.

The speed of DC motor can be controlled by two major methods, the first is a magnetic field control this method is used in separately excited DC motors and cannot be used with permanent magnet motors [3]. The second is armature voltage control. In this work, the second method is used because the chosen motor is permanent magnets DC motor (PMDC). These motors are used in applications that require compact size and fractional horsepower where they are manufactured at low cost. There are several techniques of DC motor speed control used in many practical controller applications such as by using thyristor, chopper circuit, Fuzzy Logic Controller and digital controllers [4]. In modern speed applications the digital control techniques provide a better way to realize the DC motor speed control [5].

The main purpose of the present work is to design and implement the hardware and software of open loop digital control system based on PWM to control dual DC Motor using PIC 16F877A microcontroller.

2. Modeling of PMDC Motor

The equivalent circuit shown in Figure 1 represents a permanent magnet DC motor.

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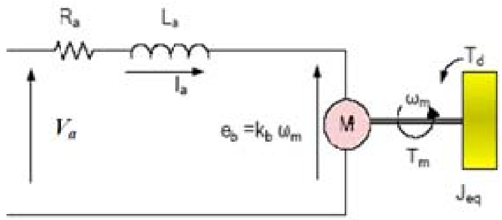

Figure 1. Modeling of PMDC motor

When the supply voltage is applied to the terminals of a PMDC motor, the armature current of i_a flows in the armature circuit, and the induced back emf and a motor torque is developed to balance the load torque at a certain speed. The terminal voltage is given by:

$$V_a = i_a R_a + L \frac{di_a}{dt} + e_b \tag{1}$$

The back emf is given by:

$$e_b = k_b \phi \omega_m \tag{2}$$

Then:

$$\omega = \frac{V_a - i_a R_a}{k_b \phi} \tag{3}$$

$$T_m = k_t \phi i_a \tag{4}$$

$$J \frac{d\omega_m}{dt} = T_m - T_d - B\omega_m \tag{5}$$

Where:

$$n = \frac{60\omega}{2\pi} \tag{6}$$

Where V_a is terminal voltage in volt, ia is armature current in amp, L is armature inductance in hennery, e_b back emf of motor in volt, R_a is armature resistance in omh, di_a /dt is rate of change of armature current in amp/sec, ω_m is motor speed in rad/sec, n is motor speed in r.p.m, Tm is motor torque in Nm, k_t is torque constant. Then, the speed control expression of dc motor is given as,

$$\omega = \frac{e_b}{k_b \phi} = \frac{V_a - i_a R_a}{k_b \phi} \tag{7}$$

In permanent magnet DC motor, the only method used to speed control is the armature voltage control method, because the providing magnetic field by the permanent magnets is constant and cannot altered. Referring to Equation 7, it is found that the speed of the motor is proportional to the armature voltage, then by controlling this voltage the motor speed can be controlled.

3. Pulse Width Modulation (PWM)

The Pulse width modulation technique is the simplest and most efficient way for speed control of DC motor [6]. It considered as one of the various methods used to control dc motor by generate analog voltage using digital signals. It used also in many applications such as control of delivered power to a load, generation of sine waveforms, and analog voltage level generation [7]. The PWM Tanique depends on deriving the dc motor by pulsed waveform (successive pulses) with "ON-OFF" logic situations as shown in Figure 2.

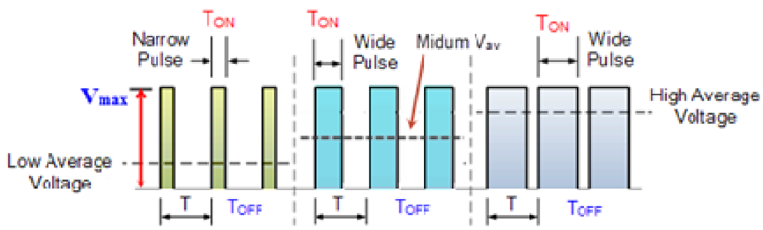

Figure 2. Pulse width modulation technique

In this method, the average value of the motor applied voltage is changed by varying the pulse width of the driving signal. Consequently, the motor speed can be varied by changing the ratio between the pulse width or the ON time T_{on} and period time T_{period} of the applied signal which is called duty cycle and given by:

$$Duty\ cycle = \frac{Pulse\ width}{Period\ Time} \tag{8}$$

$$Duty\ cycle = \frac{T_{ON}}{T_{period}} \tag{9}$$

Then, the duty cycle can be defined as the fraction of time period for which the signal is ON to total time period [8]. The average value of the motor applied voltage V_{av} is given by:

$$V_{av} = \frac{1}{T}\int_0^T V_{rated}(t)\,dt = \frac{T_{ON}}{T_{period}} V_m \tag{10}$$

$$V_{av} = Duty\ cycle \times V_m \tag{11}$$

Where: $T_{period} = T_{ON} + T_{OFF}$, Duty cycle = T_{ON} / T_{period}, and V_m = amplitude of the motor rated voltage.

The average power and respectively the speed of dc motor can be varied by changing the duty cycle of the signal which is called pulse width modulation PWM. In this control method, the power input to the motor is switched on and off quickly with high switching rate which is enough to make the switching effects are negligible and unnoticed.

3. Microcontroller PWM Generation Technique

The generation of PWM using PIC16F877A MCU depends on its built in CCP modules which are means Capture/Compare/PWM. The PIC16F877A MCU has two (CCP) Modules, CCP1 and CCP2 at pins RC2 and RC1 of Port C respectively as shown in Figure 3. Each module (CCP1 and CCP2) contains a 16 bit register (two 8-bit registers) [8]. The two PWM registers CCPR1 and CCPR2 are belong to CCP1 and CCP2 modules respectively. The register CCPR1 is consists of CCPR1L (low byte) and CCPR1H (high byte). Similarly, the register CCPR2 has CCPR2L (low byte) and CCPR2H (high byte) [9]. The CCP1CON and CCP2CON registers controls the operation of CCP1and CCP2 respectively. The special event trigger is generated by a compare match and will reset Timer1 and start an A/D conversion (if the A/D module is enabled)[10]. The block diagram of the CCP1 and CCP2 modules and its associated registers is shown Figure 4.

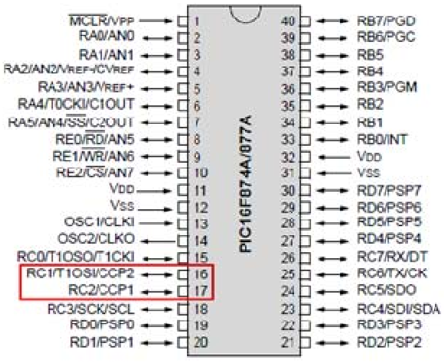

Figure 3. Microcontroller Pic16F877A pin assignment.

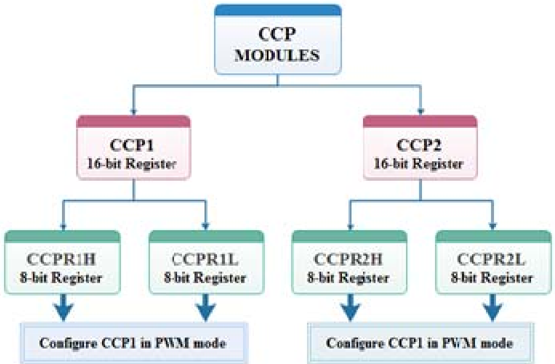

Figure 4. CCP modules associated registers.

These two modules can be configured to generate two separate and independent PWM signals with different duty cycle. The two PWM frequencies is the same for CCP1 and CCP2 because it use Timer2 as a time base. More details about the operation of CCP modules in PWM mode and timer resources are found in [8] [9] [10]. The PWM functional blocks is shown in Figure 5 and the corresponding PWM waveform timing can be seen in Figure 6 [11].

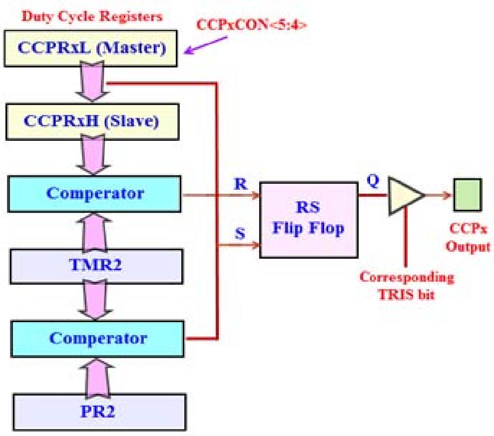

Figure 5. PWM module block diagram

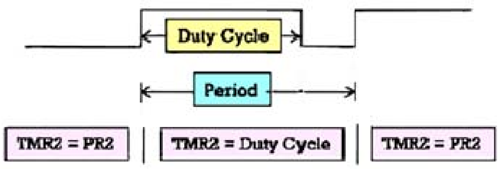

Figure 6. PWM waveform showing period and duty cycle

The duty cycle and period definitions are clear from the figure (6) itself. The PWM Period, Duty Cycle and Resolution are calculated by these formulas [9]:

$$\text{Period} = [(PR2) + 1] \times 4 \times Tosc \times (\text{TMR2 Prescale Value}) \quad (12)$$

$$\text{Duty Cycle} = (CCPR1L{:}CCP1CON\langle 5{:}4\rangle) \times Tosc \times (\text{TMR2 Prescale value}) \quad (13)$$

$$\text{Resolution} = [\log (FOSC / FPWM)] / [\log(2)] \text{ bits} \quad (14)$$

4. Dual DC Motor Driver and Control Strategy

The SN754410 driver chip shown in Figure 7 which is the quad Half-H-Bridge channel is chosen to drive the dc motors in two directions and provide them by sufficient current. It can be driving high voltage motors (from 4.5V to 36V) using TTL logic levels +5V and supply enough continuous output current up to 1A [12]. The pin assignments and connection description of the SN754410 driver chip when it used to drive the two DC motors is shown in Figure 8.

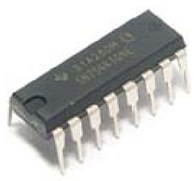

Figure 7. SN754410 driver chip

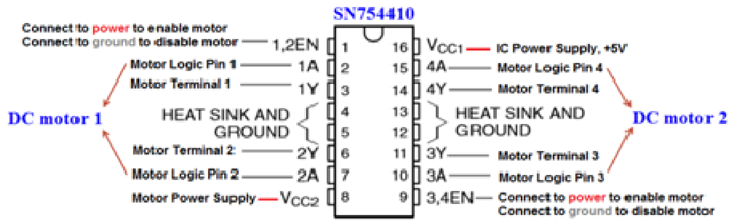

Figure 8. SN754410 Pin assignments and connection diagram

The SN754410 chip has two control inputs, one enable input and one output per each channel. The pins 1,2EN, 1A, 2A, 1Y and 2Y control the first motor on the left side while the pins 3,4EN, 3A, 4A, 3Y and 4Y control the other motor on the right side. The Control inputs (1A, 2A) and (3A, 4A) are used to control the rotation direction (clockwise or anti clockwise) for the first motor and second respectively. The enable inputs (1,2EN and 3,4EN) are used to turn the two H-bridge ON or OFF. The pins V_{CC1} and V_{CC2} are used to power the driver chip as follow: pin V_{CC1} is used to power the logic gates inside the chip by (+5V) logic supply voltage and pin V_{CC2} is used to power the motors by their rated voltages and this pin can receive up to 36V. The pins 4,5,13, and 12 must be connected to the ground (0V) and used as a heat sink. The proposed control strategy based on PWM technique by generating two independent signals using PIC16F877A microcontroller and the SN754410 driver chip is shown in Figure 9.

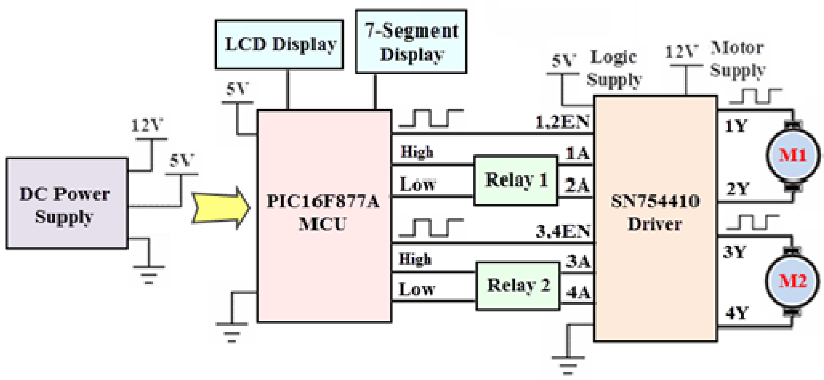

Figure 9. Proposed PWM control strategy

The dual control strategy depending upon the operation of the H-Bridge is fairly simple by identifying the logic state (High or Low) of the enable and input pins. The logic state of these control pins is determined by means of the logic values sent from microcontroller [8]. Table 1 show the behavior of the two DC motor for different input conditions.

Table 1. DC Motors behaviour with different input conditions

Enable 1,2EN 3,4EN	Inputs 1A, 3A	Inputs 2A, 4A	DC motor1 and DC motor2 Functions
1	1	0	Runs counter clockwise (left direction)
1	0	1	Runs counter clockwise (right direction)
1	1	1	Fast Motor Stop or brake
1	0	0	Fast Motor Stop or brake
0	Regardless	Regardless	Fast Motor Stops or brake

4. Dual DC motor drive system Description

The schematic diagram of the proposed dual DC motor speed control is designed and simulated by Proteus 7.10 design suite software package. The main element of the implemented control system is the PIC16F877A microcontroller is used with other electric and electronic devices as shown in Figure 10.

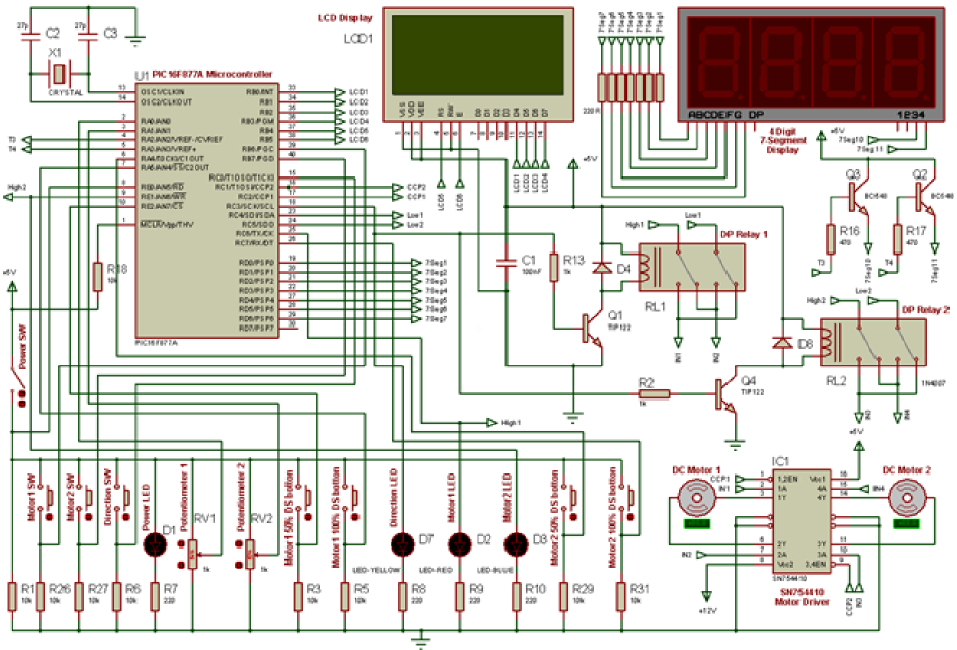

Figure 10. Schematic diagram of the Dual PWM control of DC motor designed by Proteus software

The microcontroller read the analog value of the voltage across two variable resistances (potentiometers) which are connected with two ADC (AN0 and AN1) at pins (RA0 and RA1). The change in these analog values of input voltage will change the duty cycle of the generated PWM signals which directly linked to the DC motors speeds. A four fixed speed push buttons and the two potentiometers can be varying the speed of the two DC motors according to the function of each element. The potentiometers give broad range of speed control from 0% to 100% of the maximum motor speed. The four push buttons can be adjusted manually to give more fixed values of speed which used usually such as 50% and 100%. These few values of fixed speed can be changed in the future by editing and updating the microcontroller program.

The motors driver chip SC754410 is interfaced with PIC microcontroller pins RC6, RE1, RC4, and RC5 through the outputs IN1, IN2, IN3, and IN4 of two double poles relays (DP relay1 and DP relay2) at its input terminals A1, A2, A3, and A4 respectively. The two pins RC6 and RE1 are always at HIGH logic state but RC4 and RC5 are forever at LOW logic state. The Enable pins 1,2EN and 3,4EN are connected to the generated two PWM signals at pins RC2 and RC1. The output pins Y1, Y2, Y3, and Y4 of SN754410 chip, each two of them are connected to one of the two DC motors respectively. The two double poles relays (DP relay1 and DP relay2) are used to reverse the rotation direction (clockwise or anticlockwise) of the two DC motors when the pin RC3 send signal with High logic state if the direction switch is turned on. A digital LCD (4x16) pins are connected to port B and a 4-digit 7-Segment multiplexed display unit pins are connected to port D to display the details of DC motors control modes of operation. A 5V/12V DC power supply consists of AC step down transformer 220v/12v, full wave rectifier bridge, voltage regulator, and ripple filter was implemented [13]. PIC microcontroller and SN754410 driver chip are supplied by 5V logic level, and the DC motors fed by 12V as a rated voltage.

5. Software Algorithm Implementation

The software implementation and control algorithm of the implemented dual dc motor control system was developed using Flowcode software package. Flowcode is a graphical tool used to programming the PIC microcontroller once drawing the program flowchart [8]. The flowchart of the PWM control algorithm is shown in Figure 11.

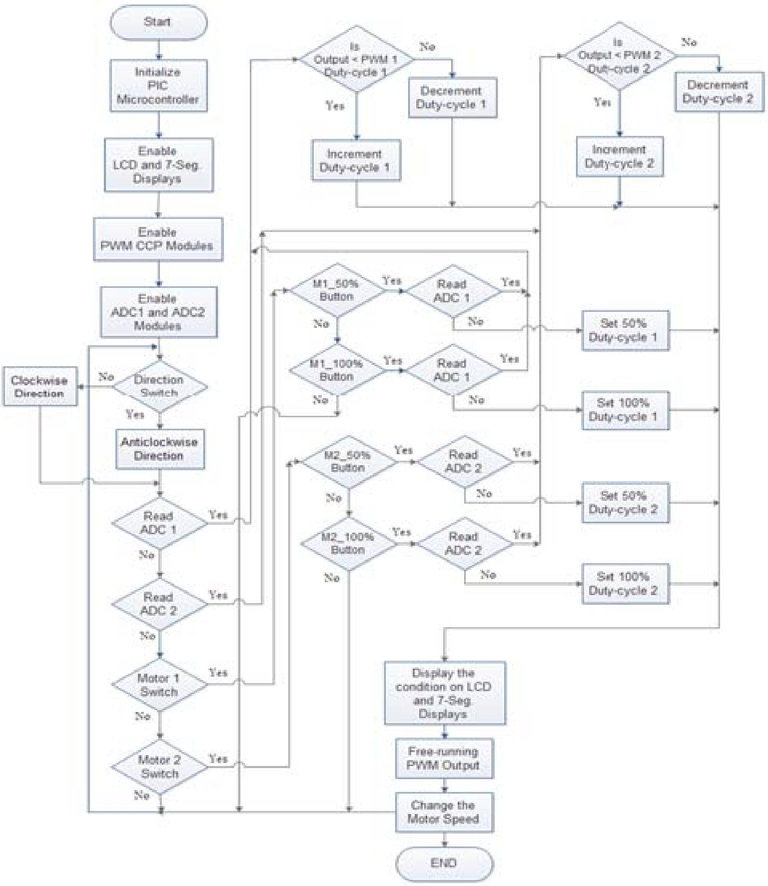

Figure 11. Flowchart of the developed control algorithm

The simulation of two motors based PWM signals using flowcode software at medium and maximum speeds with duty cycle equals 50% and 100% respectively, in two directions (anticlockwise and clockwise) using push button switches are shown in Figure 12.

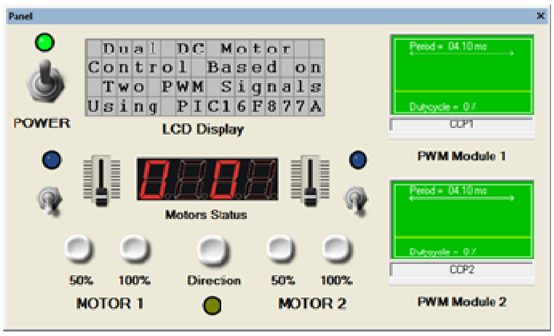

Figure 12a. Two motors at starting (PWM modules CCP1 and CCP2 have Duty cycle = 0)

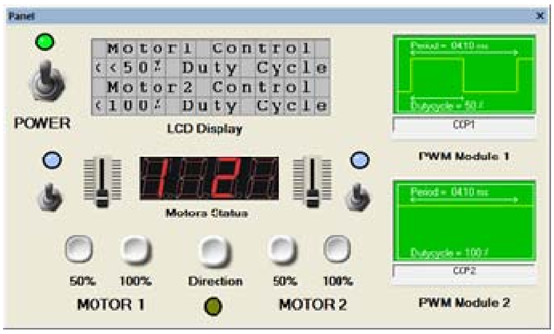

Figure 12b. Two motors runs in anticlockwise direction (CCP1 and CCP2 modules at Duty cycle equal 50% and 100% respectively

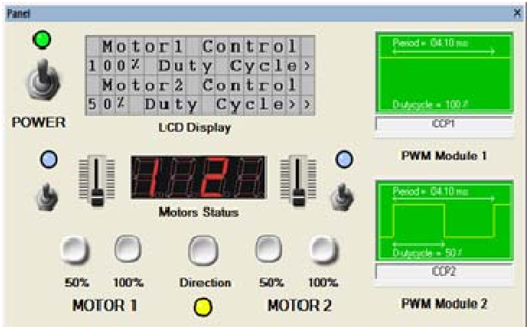

Figure 12c. Two motors runs in clockwise direction (CCP1 and CCP2 modules at Duty cycle equals 100% and 50% respectively)

Also the simulation at very low , low, equal, high, and very high speeds in different directions with duty cycle equals 10%, 25%, 65%, 75% and 90% using potentiometers are shown in Figure 13.

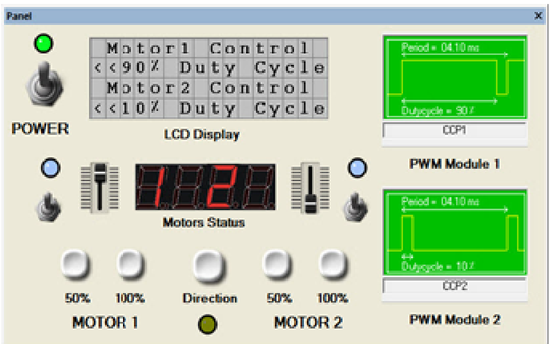

Figure 13a. Two motors runs in anticlockwise direction (CCP1 and CCP2 modules at Duty cycle equal 90% and 10% respectively)

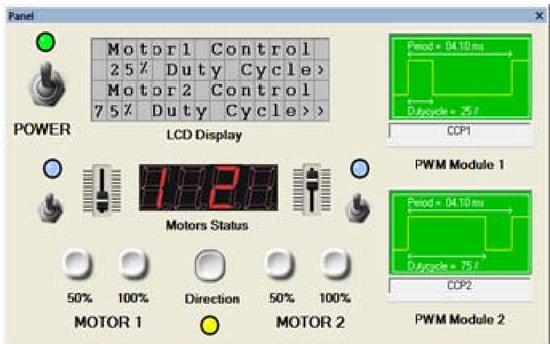

Figure 13b. Two motors runs in clockwise direction (CCP1 and CCP2 modules at Duty cycle equals 25% and 75% respectively)

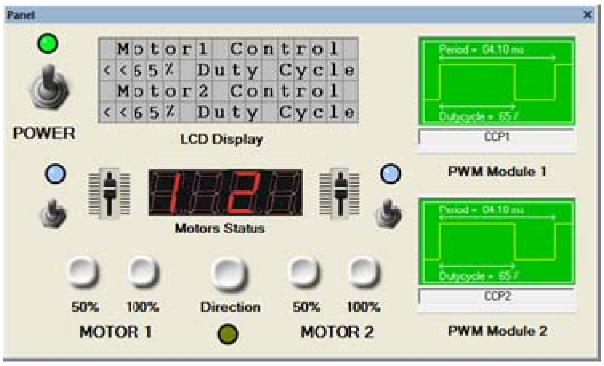

Figure 13c. Two motors runs in anticlockwise direction at the equal speed (CCP1 and CCP2 modules at same Duty cycle equal 65%)

6. Hardware Setup and Experimental Results

6.1. Hardware implementation

The hardware development setup of the implemented dual dc motor control system (rated voltage V = 12V and rated current I = 0.5A) control system using PIC16F877A microcontroller based on two independent PWM signals is shown in Figure 14.

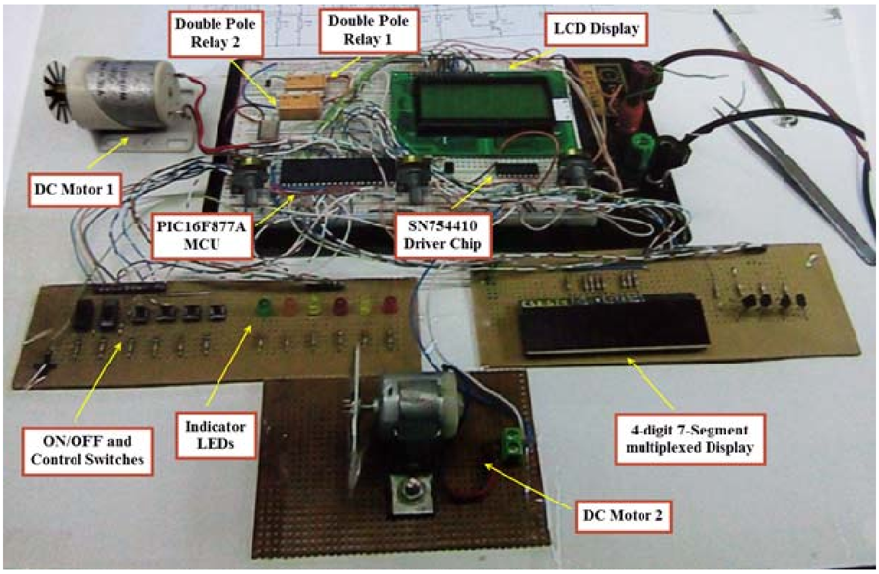

Figure 14. Photograph of hardware setup connection of PIC16F877A MCU based dual DC motor PWM control system

6.2. Simulation Results

The simulation results of the generated PWM signals was accomplished with period of 4ms and frequency of 244 Hz using proteus suite software package. The output two PWM signals of the two modules CCP1 and CCP2 at pins RC2 and RC1 for different values of duty cycle are shown in Figure 15. The same duty cycle values of 5%, 25%, 50%, 75%, and 100% was chosen for the two PWM signals in order to rotate the two motor at the same speed. The oscilloscope upper trace is PWM1 signal while the lower trace is PWM2 signal and Horizontal: 1 msec/div. Vertical; 2 volt/div.

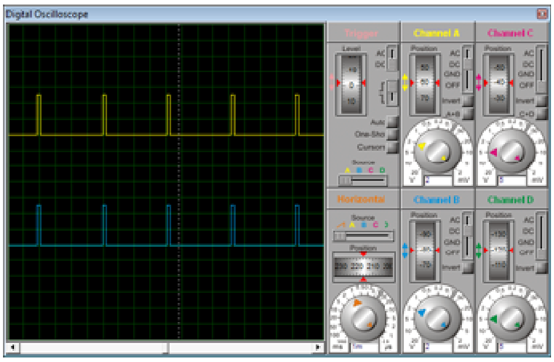

Figure 15a. Output two PWM signals at duty cycle 5%. (The two motors rotates at the same very low speed)

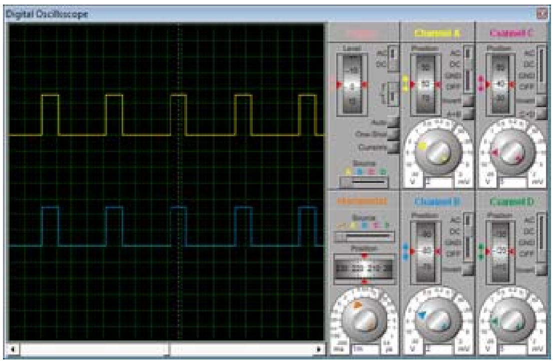

Figure 15b. Output two PWM signals at duty cycle 25%. (The two motors rotates at the same low speed)

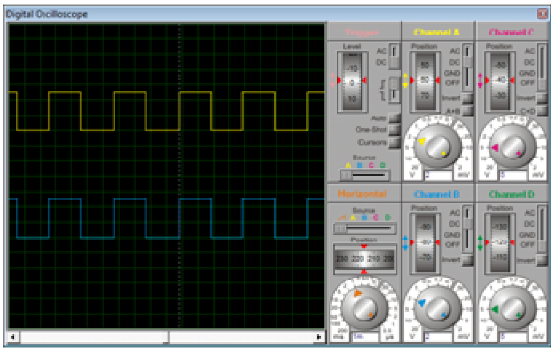

Figure 15c. Output two PWM signals at duty cycle 50%. (The two motors rotates at the same Medium speed)

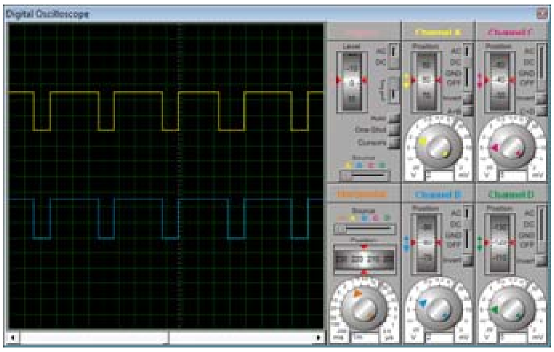

Figure 15d. Output two PWM signals at duty cycle 75%. (The two motors rotates at the same very high speed)

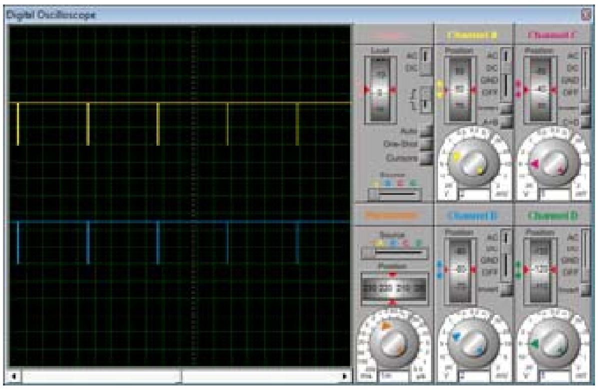

Figure 15e. Output two PWM signals at duty cycle 100%. (The two motors rotates at the same Maximum speed)

The simulation of the output two PWM signals and the corresponding terminal voltages of the two DC motors for various values of duty cycle with oscilloscope (Horizontal: 2 msec/div. Vertical; 5 volt/div) are shown in Figure 16.

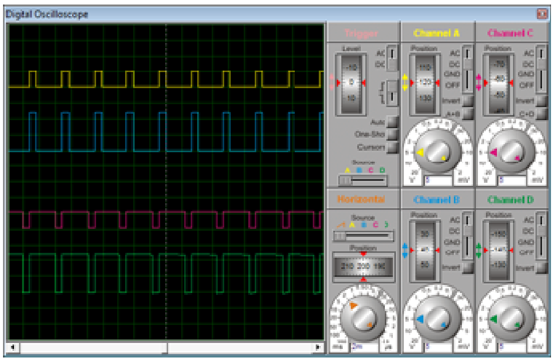

Figure 16a. PWM signals and terminal voltage at duty cycle 20% and 80% (speed $n_1 < n_2$). Upper Trace: PWM1 signal and Motor1 terminal voltage (Vav = 2.4V) Lower Trace: PWM2 signal and Motor2 terminal voltage (Vav = 9.6V)

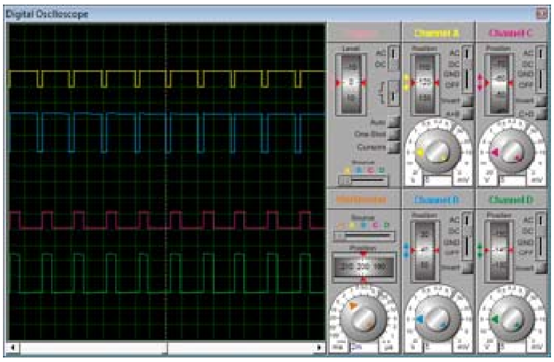

Figure 16b. PWM signals and terminal voltage at duty cycle 85% and 30% (speed $n_1 > n_2$). Upper Trace: PWM1 signal and Motor1 terminal voltage (Vav = 10.2V) Lower Trace: PWM2 signal and Motor2 terminal voltage (Vav = 3.6V)

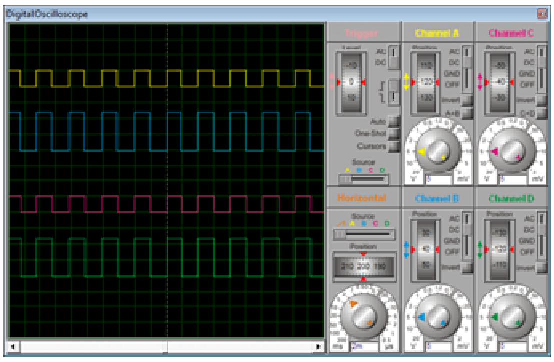

Figure 16c. PWM signals and terminal voltage at duty cycle 50% and 50% (speed $n_1 = n_2$). Upper Trace: PWM1 signal and Motor1 terminal voltage (Vav = 6V) Lower Trace: PWM2 signal and Motor2 terminal voltage (Vav = 6V)

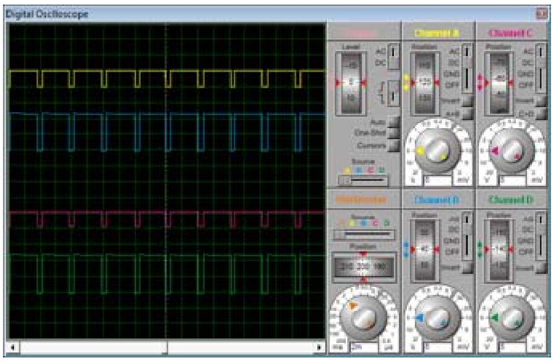

Figure 16d. PWM signals and terminal voltage at duty cycle 95% and 95% (speed $n_1 = n_2$). Upper Trace: PWM1 signal and Motor1 terminal voltage (Vav = 11.4V) Lower Trace: PWM2 signal and Motor2 terminal voltage (Vav = 11.4V)

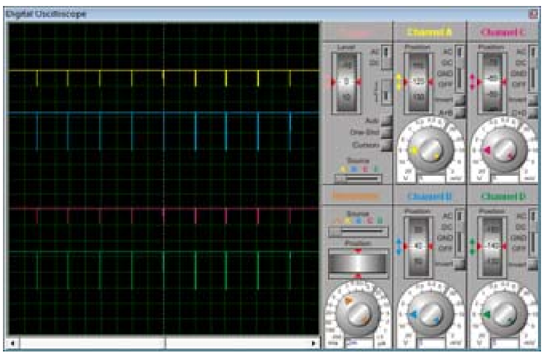

Figure 16e. PWM signals and terminal voltage at duty cycle 100% and 100% (speed $n_1 = n_2$). Upper Trace: PWM1 signal and Motor1 terminal voltage (Vav = 12V) Lower Trace: PWM2 signal and Motor2 terminal voltage (Vav = 12V)

6.3 Hardware Results

The Hardware results of the implemented control system using real oscilloscope for the two generated PWM signals at the same period and frequency (period of 8ms and frequency of 125 Hz) with different values of duty cycle are shown in Figure 17.

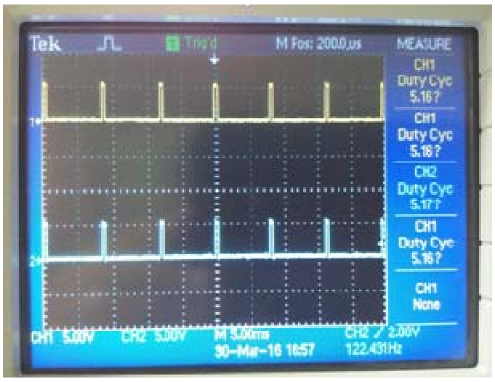

Figure 17a. Two generated PWM signals at duty cycle 5%. (Motors rotates at same very low speed)

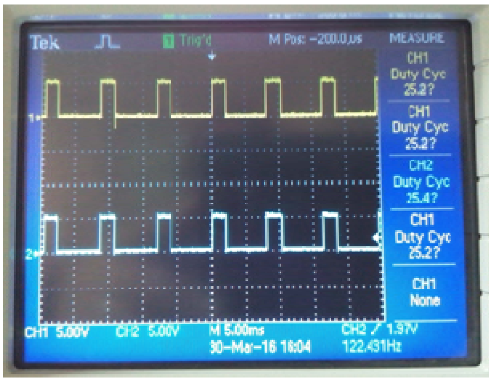

Figure 17b. Two generated PWM signals at duty cycle 25%. (Motors rotates at same low speed)

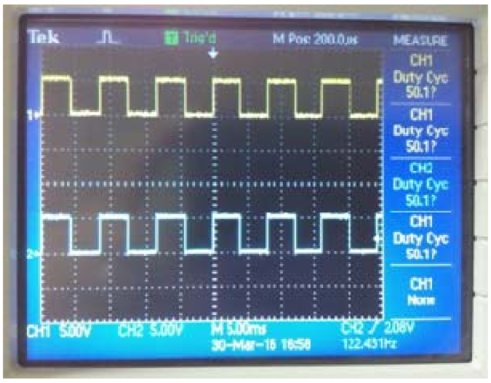

Figure 17c. Two generated PWM signals at duty cycle 50%. (Motors rotates at same medium speed)

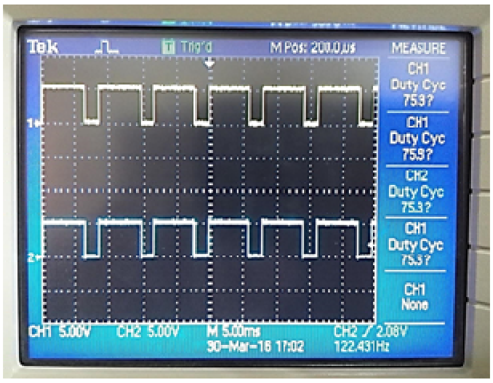

Figure 17d. Two generated PWM signals at duty cycle 75%. (Motors rotates at same high speed)

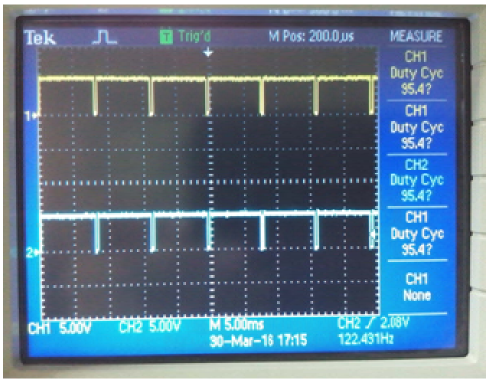

Figure 17e. Two generated PWM signals at duty cycle 95%. (Motors rotates at same very high speed)

The hardware oscilloscope results of the two generated PWM signals and the corresponding terminal voltage of the two DC motors for different values of duty cycle are shown in Figure 18.

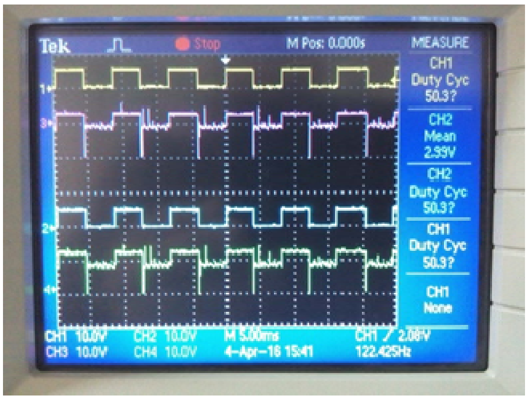

Figure 18a. PWM signals and motors terminal voltage at duty cycle 50% and 50% (speed $n_1 = n_2$)

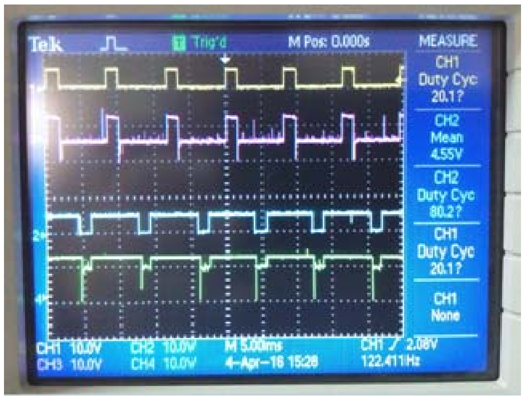

Figure 18b. PWM signals and motors terminal voltage at duty cycle 20% and 80% (speed $n_1 < n_2$)

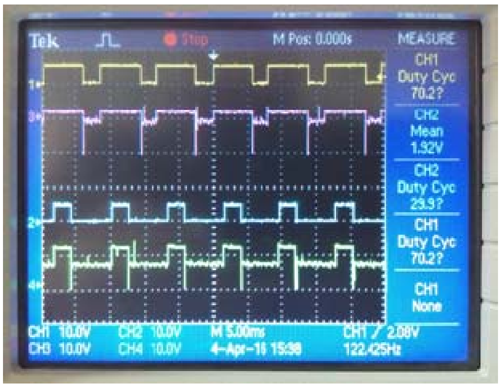

Figure 18c. PWM signals and motors terminal voltage at duty cycle 70% and 30% (speed $n_1 > n_2$)

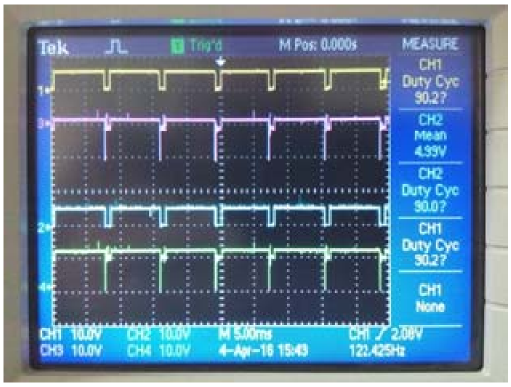

Figure 18d. PWM signals and motors terminal voltage at duty cycle 90% and 90% (speed $n_1 = n_2$)

The measured values of the controlled output terminal voltage and the calculated output voltage using equation 11 with various values of duty cycles are shown in Table 2.

Table 2. DC Motor terminal voltage at different duty cycles

Duty Cycle (%)	Calculated output voltage (V)	Measured output voltage (V)	Motor terminal voltage (V)
10	1.2	2.92	1,48
20	2.4	4.17	5.1
30	3.6	5.43	7.25
40	4.8	6.34	8.49
50	6	7.49	9.31
60	7.2	8.59	9.83
70	8.4	9.68	10.2
80	9.6	10.8	10.8
90	10.8	11.7	11
100	12	12	11.3

The average value of the generated PWM output voltage is measured as analog signal using the low pass filter with its cutoff frequency higher than the PWM signal frequency. This low pass filter which simply consists of RC circuit is used to filter out the fundamental and higher harmonics components of the PWM single and only the DC component of slowing variation passed through the filter. The relations between the duty cycle versus Calculated output voltage, Measured output voltage, and motor terminal voltage are shown in Figure 19, Figure 20, and Figure 21 respectively.

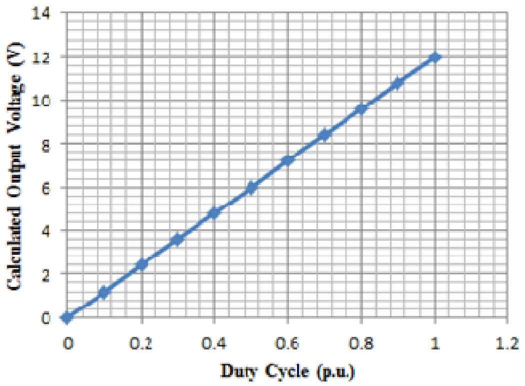

Figure 19. Duty cycle and calculated output voltage

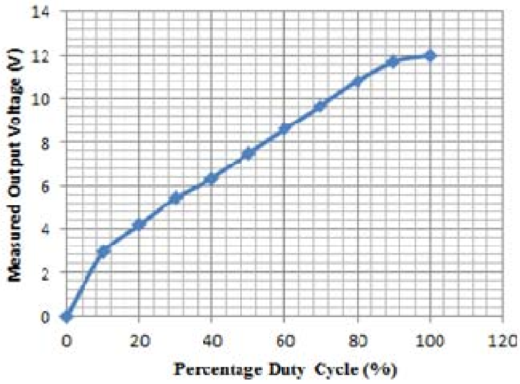

Figure 20. Duty cycle and measured output voltage

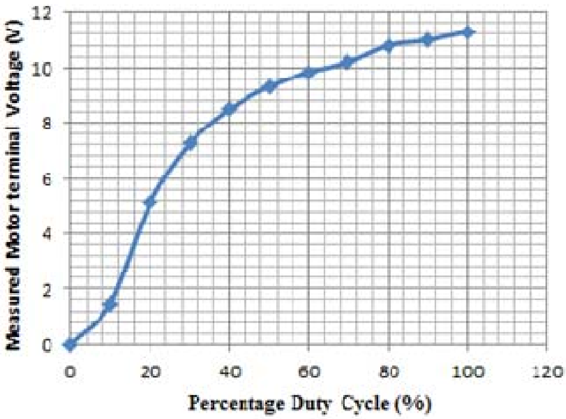

Figure 21. Duty cycle and measured motor terminal voltage

7. Conclusion

The goal of this paper is to design, simulation and practical implementation of dual DC motor speed control system based on two independent PWM signals using PIC16F877A MCU. The embedded CCP modules of the MCU have been programed to generate the digital PWM signals with various duty cycles. The control system was simulated with PWM period of 4ms and frequency of 244 Hz and the hardware setup was practically implemented with PWM period of 8ms and frequency of 125 Hz. The simulation and experimental results confirm that the DC motors are operated at varies speeds by changing the PWM duty cycles. The proposed technique of the open loop real time PWM control system of small DC motors can also be developed to drive larger motors by replacing the drive circuit. The control system features are easy to implement with low cost, simplicity, low hardware setup, Flexible development in future, and efficient operation. An Excellent agreement was achieved between the experimental and simulation results. The proposed digital control system is suited for industrial applications and gives better control performance and high accuracy of control.

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