Design of a Microcontroller-Based Photo-Controlled Circuit for Adjusting the Speed of DC Motors

(Assist. Lecturer)Firas Mohammed Ali Al-Raie*

Abstract

There are many approaches and methods for changing the speed of DC motors. One of these approaches is through the intensity of light. In this paper, a microcontroller-based control circuit for adjusting the speed of a DC motor by means of interrupting the incident light is proposed and implemented. The adopted technique in this circuit uses two light dependent resistors as photo-sensors to detect the illumination of light by producing a prescribed digital sequence to activate one of the input ports of an 8051 microcontroller. An assembly program stored in the on-chip program memory of the microcontroller generates the proper PWM signal at an output port based on the received sequence. This signal is supplied to the driving circuit of the motor in order to run it with the relevant speed. The circuit has been implemented and tested successfully in the laboratory.

Keywords: 8051 Microcontroller, Motor Speed Control, PWM, Photo-sensors.

---

* Electrical Engineering Dept., University of Technology

1. Introduction

The speed of DC motors can be controlled automatically with the aid of microcontrollers. In order to implement the interfacing process between a DC motor and the microcontroller, it is required to design an electronic circuit to connect the motor into one of the microcontroller ports. This circuit is utilized to direct the flow of signals outgoing from or incoming to the microcontroller's port. In addition, a program should be written and saved in the microcontroller's memory to control the motor speed automatically from the port of the microcontroller. In industrial applications, different types of sensors are used to detect light, temperature, pressure, humidity ...etc to change the motor ON/OFF switching state, direction of rotation, and speed level.

The work in this paper is concerned with the adjustment of DC motor's speed depending on the intensity of the light falling on certain photo-sensors.

2. Classical Methods of DC Motor Speed Control

DC motor speed depends on three factors: load, input voltage, and field current [1]. For a given fixed load, there are in general three techniques used for DC motor speed control. The choice of the specific method depends on the required application. These methods are the field current control method, input voltage control method, and the pulse width modulation method.

2.1 Field Current Control Method

It is well-known that the rotational speed of DC motors is inversely proportional to the magnetic field around their poles. By adding a variable resistance in series with the field winding, the field current and thereby the magnetic flux of poles can be changed [1]. Accordingly, the motor speed can also be varied. However, this method is used in separately excited DC motors and cannot be used with permanent magnet motors.

2.2 Input Voltage Control Method

The speed of DC motors is dependent on the supply input voltage. When changing the applied voltage, the motor speed can thereby be varied. A potentiometer can be inserted in series with the motor and the voltage source to reduce or increase the net input voltage supplied to the motor [1].

2.3 Pulse Width Modulation Method

This method is the most efficient one for varying DC motor speed. According to this method, the average value of the applied voltage is changed by applying a pulsed waveform to the motor with variable pulse width as shown in Figure 1. This technique is known as *Pulse Width Modulation* (PWM). As shown from Figure 1, the average value of the applied voltage increases with the increase in pulse width. Based on this fact, the motor speed can be changed by varying the ratio between the pulse width τ and period T of the applied signal [2]. The average value of the applied voltage is given by:

$$V_{dc} = \frac{\tau}{T} \times V_{max} \qquad (1)$$

Where V_{max} is the amplitude of the applied pulse signal.

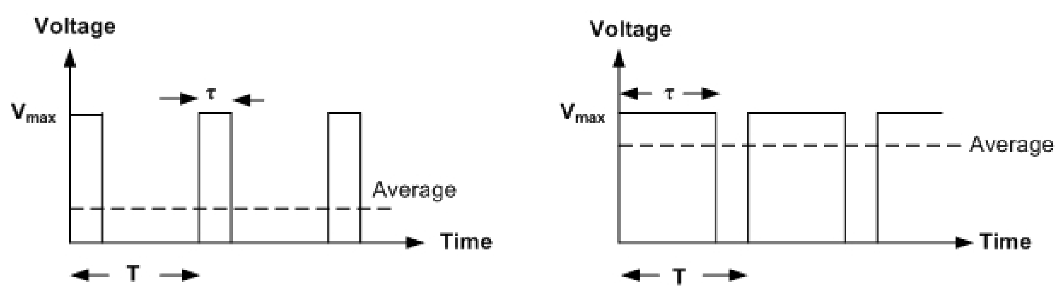


Figure 1: Pulse Width Modulated Signals

On the other hand, the duty cycle is given by:

$$Duty\ Cycle = \frac{\tau}{T} \times 100 \qquad (2)$$

By changing (modulating) the width of the pulse applied to the DC motor, the amount of power provided to the motor cab be decreased or increased and thereby increasing or decreasing the motor speed. It is clear from Figure 1 that, although the voltage has a fixed amplitude, it has a variable duty cycle. That means the wider the pulse, the higher the speed. Figure 2 shows the signals provided to the motor for different duty cycles [3].

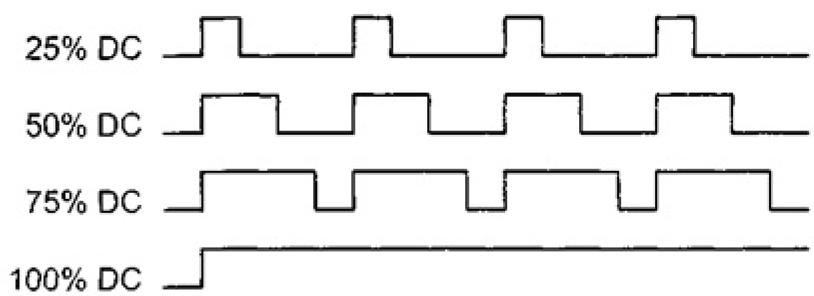


Figure 2: PWM Signals with Different Duty Cycles

3. The 8051 Microcontroller

The 8051 microcontroller is a powerful, highly flexible cost-effective solution to many embedded control applications. The 8051 microcontroller can deliver a high performance with different choices of configurations and options matched to the specific needs of each application [4]. One major feature of the 8051 microcontroller is the versatility built into the I/O circuits that connect the microcontroller to the outside world. It has four I/O ports, each containing 8-bits. It can also be interfaced with the PC via a built-in serial port. The AT89C51 is an improved version of the original 8051 microcontroller with a built-in flash memory of size 64 KB for user program storage. It can be erased and reprogrammed easily using a universal programmer. In this work, the AT89C51 microcontroller chip has been used in the design of the control circuit.

4. Photo Sensor Circuits

Photo resistors, also known as light dependent resistors (LDR), are light sensitive devices most often used to indicate the presence or absence of light, or to measure the light intensity. In the dark, their resistance is very high, sometimes up to 1MΩ, but when the LDR sensor is exposed to light, the resistance drops dramatically, even down to a few ohms, depending on the light intensity. LDRs have a sensitivity that varies with the wavelength of the light applied and are nonlinear devices [5].

Figure 3 presents a typical photo-sensor circuit using an LDR [6]. When the light level on the LDR is low, the resistance of the LDR is high. This prevents current from flowing to the base of the transistor. Consequently, the collector voltage of the transistor is high (V_{CC}). However, when light intensity onto the LDR increases, its resistance falls and current flows into the base of the transistor. This will turn-on the transistor and makes its collector voltage low.

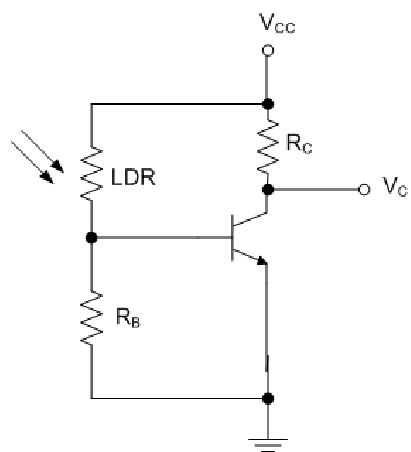


Figure 3: A Typical Photo Sensor Circuit

5. The 8051 Microcontroller-Based DC Motor Speed Control Circuit

In this work, an 8051 microcontroller-based control circuit for adjusting the speed of a small permanent magnet DC motor via photo-sensors is proposed. The aim of this circuit is to vary the speed of the motor in different levels depending on two photo sensors connected to the microcontroller. The microcontroller input port (Port 1) senses the voltage levels of each of the photo sensor circuits, while the program stored in the microcontroller's memory produces the necessary PWM signal at its output port (Port 2) to drive the motor circuit. The block diagram for this circuit is presented in Figure 4.

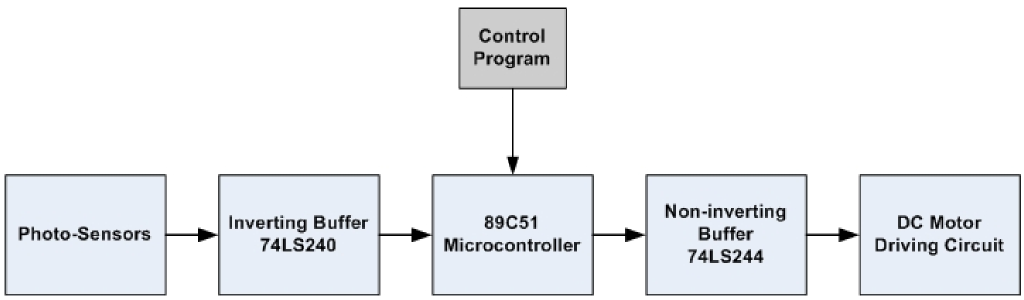


Figure 4: A Block Diagram for the Proposed Control Circuit

Figure 5 shows the schematic diagram of the control circuit. The speed of the motor can be adjusted by the light intensity falling into the photo resistors LDR1 and LDR2. These resistors control the bias points of two transistors connected to Port 1 of the AT89C51 via an input inverting buffer (74LS240). The base and collector resistors of the photo-sensor circuit were chosen empirically to set the transistor in cut-off and saturation regions properly. The output signal from Port 2 of the microcontroller is delivered to the motor circuit with the aid of a non-inverting buffer (74LS244).

When there is no light incident on either of the LDRs, its resistance will be large (reaching to 1MΩ approximately) and thereby turning the transistor OFF. In this case, the collector voltage of this transistor will be high (+5 V). On the other hand, when the light brightness increases on the photo resistor, its resistance will decrease (to about 1kΩ at full-light illumination) and thereby causing the NPN transistor (2N2222) connected with it to switch ON. In this case, the collector voltage of the transistor will be low.

The inverting buffer 74LS240 is used to invert the signal levels at the nodes of the transistors' collectors. When either of the two transistors is ON, the signal at the input of the buffer (A1 or A2) is at logic-0 (grounded), and in this case the buffer output (YA1 or YA2) is HIGH. On the other hand, when the transistors become OFF, then the corresponding output of the buffer is LOW. This buffer is also used to protect Port 1 of the 8051 microcontroller.

The 74LS244 buffer is used to protect Port 2 of the 8051 microcontroller from the motor circuit and to provide a sufficient current to drive the output transistor. The DC motor is connected to a 5 V DC supply via the driving transistor. A free-wheeling diode is connected across the DC motor to protect the transistor from any back-induced voltage. The capacitor shown in the motor circuit is useful to remove the EMI and noise produced during motor operation.

When the output signal from pin P2.0 is set HIGH (Logic-1), current passes through the buffer and the base of the driving transistor. This will turn-on the driving transistor and the DC motor. The signal generated at pin P2.0 is a pulse-width modulated waveform to control the average voltage provided to the motor, by controlling the switching-on time of the driving transistor. This signal is generated by the control program stored in the program memory of the 8051 microcontroller.

6. Development of the Control Software

In order to run the DC motor from the microcontroller, an 8051 assembly program has been written and assembled with the aid of the ASEM-51 assembler. This program is used to control the speed of the DC motor in three levels depending on the PWM signal generated by the microcontroller at pin P2.0. The selection of the required speed is achieved by controlling the light falling on photo resistors LDR1 and LDR2 as illustrated in Table-1. Port 1 is defined as input port, while Port 2 is left as an output port. The received signal from Port 1 is masked with the binary number 00000011 using the ANL logic instruction to check the value received by Port 1 depending on the states of the photo sensors. This value is compared with 00, 01, 02, and 03 respectively to send the appropriate PWM signal into the motor circuit. A delay subroutine is included to produce the necessary delay times for the required PWM signals. Figure 6 presents the code of the developed program. This program was converted into a hex machine-code file using the ASEM-51 assembler, and then burned into the flash memory of the AT89C51 with the aid of a commercial universal programmer.

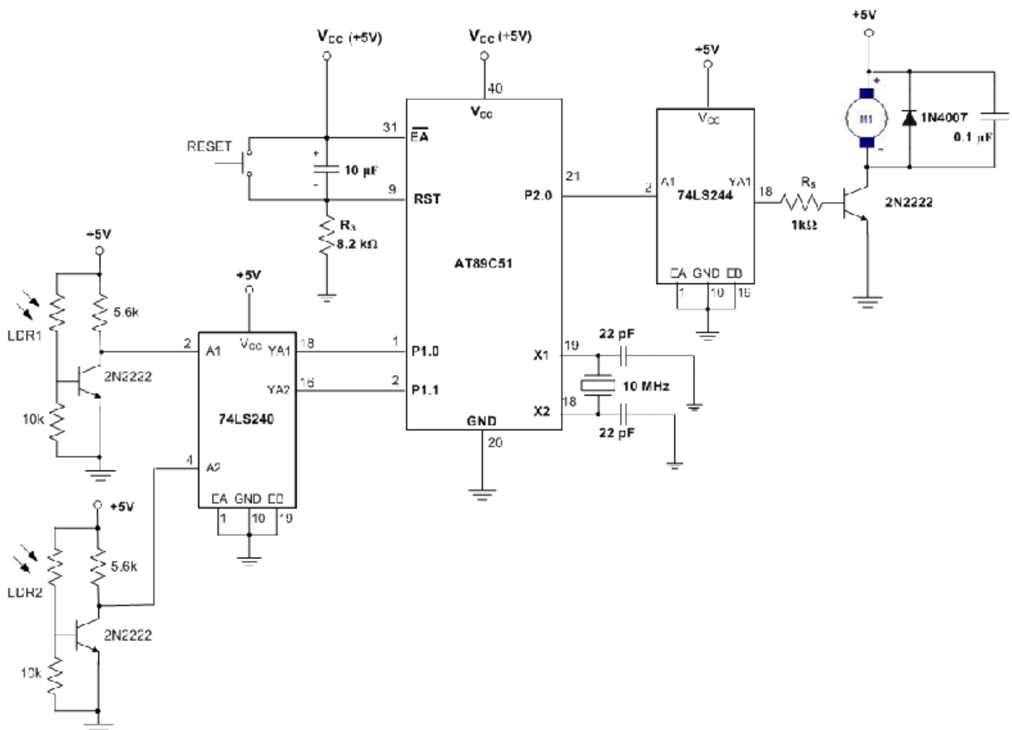


Figure 5: The Proposed DC Motor Control Circuit

Table-1: DC Motor Speed Levels

LDR2	LDR1	Duty Cycle	Motor Speed
OFF	OFF	0%	Standstill
OFF	ON	25%	Minimum
ON	OFF	50%	Medium
ON	ON	100%	Maximum

7. Circuit Implementation and Testing

The practical control circuit has been implemented using electronic test boards as depicted in Figure 7, and then tested successfully. When implementing the practical circuit, only one buffer IC has been used with the second omitted through the use of two inverting channels (A3-YA3, A4-YA4) of the 74LS240 connected in series to produce one non-inverting channel which has been connected to the base of the driving transistor.

```
motor - Notepad
File  Edit  Format  View  Help
; DC MOTOR SPEED CONTROL
                ORG 00H
                MOV P1, 0FFH
    BEGIN:      MOV A, P1
                ANL A, #03
                CJNE A, #00, SPEED1
                CLR P2.0
                SJMP BEGIN
    SPEED1:     CJNE A, #01, SPEED2
                SETB P2.0
                ACALL DELAY
                CLR P2.0
                ACALL DELAY
                ACALL DELAY
                ACALL DELAY
                SJMP BEGIN
    SPEED2:     CJNE A, #02, SPEED3
                SETB P2.0
                ACALL DELAY
                ACALL DELAY
                CLR P2.0
                ACALL DELAY
                ACALL DELAY
                SJMP BEGIN
    SPEED3:     SETB P2.0
                SJMP BEGIN
    DELAY:
                MOV R0, #0FFH
    H1:         NOP
                DJNZ R0, H1
                RET
    HERE:       SJMP HERE
                END
```

Figure 6: The 8051 Assembly Program Used to Control the Speed of the DC Motor

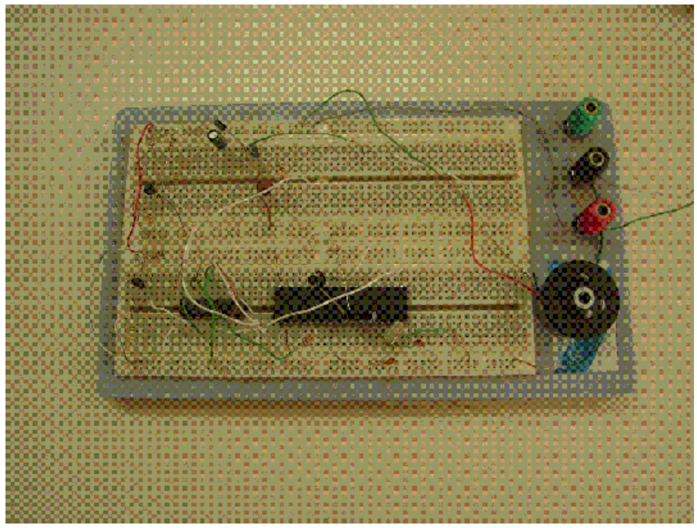
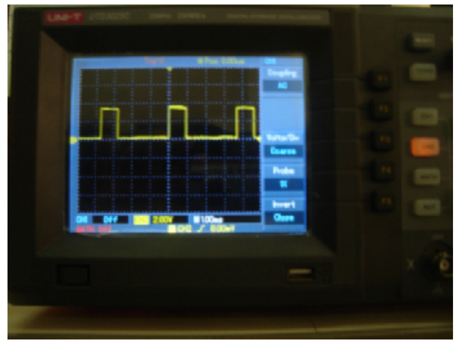


Figure 7: The Implemented Control Circuit

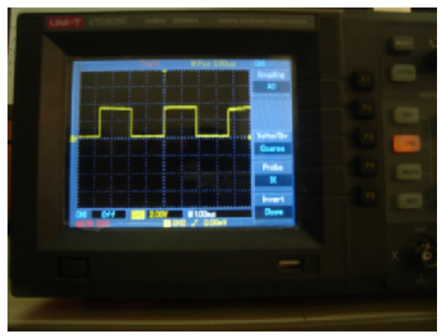
Figure 8 displays the 8051 generated waveforms at the input of the DC motor driving circuit for the three speeds using a digital oscilloscope. The drop in the amplitude of the pulses is due to the loading effect of the input impedance of the driving circuit.

8. Summary and Recommendations

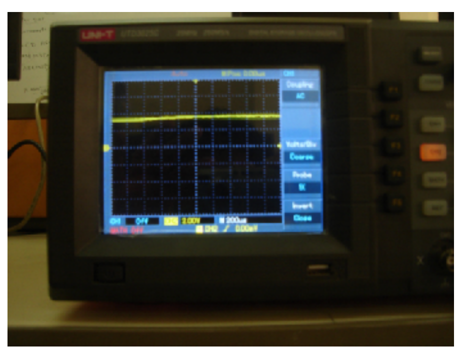
As a summary, a microcontroller-based interface circuit for adjusting the speed of a permanent magnet DC motor by means of photo-sensors has been proposed and implemented successfully. The adopted technique of the circuit relies on detecting the light intensity at two photo-resistors to activate one of the input ports of an 8051 microcontroller. An assembly program is developed and stored in the program memory of the microcontroller to generate the appropriate PWM signal based on the received digital sequence at its input port. The generated signal is supplied to the driver circuit of the DC motor to run it with the appropriate speed depending on the status of the photo-sensors.



(a) Low Speed (25% Duty Cycle PWM Signal)



(b) Medium Speed (50% Duty Cycle PWM Signal)



(c) Full Speed (100% Duty Cycle PWM Signal)

Figure 8: Microcontroller Generated Waveforms for the Three Proposed Motor Speeds

The motor speed levels can be increased by increasing the number of the photo-sensors connected to the input port of the microcontroller. This will, however, increase the complexity of the circuit. The flexibility and versatility of the control software can be extended by interfacing the 8051 microcontroller with a PC through the RS232 communication port. A user friendly graphical interface can be designed with a more advanced programming language such as *C sharp* (C#) or *Visual C++*. For multi-functional tasks, a more powerful microcontroller can replace the conventional 8051 chip.

This circuit can find applications in light tracking systems for adjusting the speed of the tracking motor depending on the intensity of the incident light. It can also be modified easily to control more than one motor at the same time.

References

[1] J. Hindmarsh, and A. Renfrew, "*Electrical Machines and Drive Systems"*, Newnes Publishing Company, 3rd Edition, 1997.

[2] Akshay Mathur, "Microcontroller-Based DC Motor Speed Controller", *Electronics For You Magazine*, March 2008, pp. 92-96.

[3] Muhammad Ali Mazidi, Janice G. Mazidi, and Rolin D. McKinlay," *The 8051 Microcontroller and Embedded Systems Using Assembly and C"*, 2nd Edition, Prentice-Hall, New-Delhi, India, 2006.

[4] Jayshree Sahu, S.K. Sahu, and J. Kumar, "Microcontroller Based DC Motor Control", *International Journal of Engineering Research & Technology (IJERT)*, Vol.1, Issue 3, May 2012, pp. 1-4.

[5] Michael Tooly, "*Electronic Circuits: Fundamentals and Applications"*, Newnes Publishing Company, 2nd Edition, 2002.

[6] Owen Bishop, "*Electronics: Circuits and Systems"*, Elsevier Ltd., 4th Edition, 2011.

تصميم دائرة تحكم ضوئي باستخدام المسيطر الدقيق لتغيير سرعة محركات التيار المستمر

م.م. فراس محمد علي الراعي*

المستخلص

هنالك عدة أساليب وطرق لتغيير سرعة محركات التيار المستمر. إن إحدى هذه الأساليب هي من خلال تغيير شدة إضاءة الضوء الساقط. تم في هذا البحث اقتراح وتنفيذ دائرة تحكم بسرعة محرك تيار مستمر صغير باستخدام المسيطر الدقيق 8051 وذلك عن طريق تغيير شدة إضاءة الضوء الساقط. تعتمد تقنية الدائرة المتبعة على إستخدام متحسسين ضوئيين لكشف مدى شدة الضوء الساقط عليها لغرض توليد تتابع رقمي محدد يتم إدخاله إلى إحدى قنوات الإدخال للمسيطر الدقيق. واعتماداً على هذا التتابع الرقمي يتم توليد إشارة نبضية معدلة عن طريق برنامج مكتوب بلغة التجميع ومخزون في الذاكرة الدائمية لرقاقة المسيطر، ومن ثم يتم تسليط هذه الإشارة عبر واحدة من قنوات الإخراج لرقاقة المسيطر الدقيق على دائرة تشغيل المحرك لتدويره بالسرعة المرغوبة. تم بناء واختبار الدائرة بنجاح في المختبر.

*قسم الهندسة الكهربائية، الجامعة التكنولوجية