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Design and Construction of PIC-Based DC Motor Speed Controller for Small Robots

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ABSTRACT

Because of their good speed control and high torque, DC motors are widely used in many industrial and robotic applications. Robotic application of DC motors often required, in addition to driving loads at constant speed or torque, the ability to vary the speed of the motor. An efficient and economically feasible intelligent DC motor speed controller is designed and constructed based on the rules of closed loop feedback control system. There are two main parts in the hardware development: PIC16F873A microcontroller and its support circuitries and external interface circuitries between motors and microcontrollers. Data processing and control program (firmware program) was run on PIC microcontroller and its on-chip A/D converter, PWM module and external circuitry was used to send and receive the data signal from the motor for control application. The firmware program was written in assembly language and converted to machine language (Hex code) by using Microchip MPASM macro assembler. These machine codes are downloaded into the PIC microcontroller by using EPIC microcontroller programmer. Through prototyping and implementing on a PIC microcontroller, the system was then be tested and used to control the speed of a small DC motor until the required criteria were achieved.

Keywords : PIC, DC, Program, A/D converter and Speed

I. INTRODUCTION

Industry automation is mainly developed around motion control systems in which controlled electric motors play a crucial role as heart of the system. Therefore, the high performance motor control systems contribute, to a great extent, to the desirable performance of automated manufacturing sector by enhancing the production rate and the quality of products. In fact the performance of modern automated systems, defined in terms of swiftness, accuracy, smoothness and efficiency, mainly depends to the motor control strategies. The advancement of control theories, power electronics and microelectronics in connection with new motor designs and materials have contributed largely to the field of electric motor control for high performance systems. In this project a small robot which can move with various speeds and directions is designed and constructed. Its movements can be controlled by a universal remote control from a distance. The robot able to move forward and reverse directions with different speeds and it can rotate to the left and right direction of up to twenty degree. The robot is constructed by using precision DC motor and the control instructions are written by assembly language and preinstalled in a microcontroller.

The electric motor is a machine that can transform electricity into rotary motion to perform useful work. As such, the electric motor represents one of the great advances in harnessing natural forces to do work for mankind.

Man first replaced his own muscle power with that of animals and then with power derived from the available natural forces of wind and water. And when Volta developed the first battery, a new form of power called electric power was developed. This was the first step in the development of the electric motor [1].

Motors vary in size, shape and functionality. There are three types of mtor:

(i) DC motor
(ii) Stepper motor and
(iii) AC motor.

DC motors are used for small hobby purposes to medium size appliances (e.g., handheld drill) and a DC voltage source (e.g., battery). It is easy to control. DC motors are commonly used in hobby situations and robotics. They are cheap, robust and easy to use. DC motors are commonly used to operate machinery in a variety of applications. DC motors were one of the first types of energy converters used in industry. It is important that earliest machines required speed control and DC motors could have their speed changed by varying the voltage sent to them.

1.1 DC Motor Construction

DC motor are made up wrapping coils of wire around a post. These windings are placed inside a magnetic field (created by permanent magnets or electromagnets). When a voltage is applied to the windings, a current will go through the coil, which will create another magnetic field. The two magnetic fields may attract each other (like two opposite poles of magnets) or repel each other (like two similar poles of magnets). This will cause the windings to move and rotate the central shaft of the motor.

After making a half rotation, the current going through the windings will go in reverse (due to a switch known as the commutator ring) and the motor will continue spinning.

Anyway, the two most important things for this document are:

(i) DC motors have windings and
(ii) The current in the windings change every rotation.

1.2 DC Generator (Speed Detection Motor)

Generators (dynamos) range in size from the small dynamos that provide current for cycle lights to the huge alternators that supply mains electricity to homes and factories. All make use of electromagnetic induction. Many are based on the simple principle that a current can be induced in a coil by rotating it in a magnetic field [2].

The input to a generator, then, is the mechanical energy needed to rotate the conductors. This energy can be supplied by gasoline or diesel engines, steam turbines, electric motors, flowing water or even atomic reactors. In fact, anything that can be used to make a shaft rotate can be the input to an electrical generator. The output of a generator is the electromotive force (emf) induced in the conductors as they move through the magnetic field. Since a generator requires a magnetic field for its operation, a generator might also be defined as a device that converts mechanical energy into electrical energy by means of a magnetic field or by magnetic induction [3].

1.3 Speed Control Parameters

The speed control parameters are:
(i) Speed reference value
(ii) Control rate value (Acceleration and Deceleration) and
(iii) Control period.

These values will be changed with the characteristic of the main motor and speed detection motor. In case of the motor, even if the drive electric current changes, the rotational speed doesn't shift immediately. Because of the mass of the rotor of the motor. In case of the small motor, the rotating speed shifts quickly by the change of the drive electric current. In case of the big motor, it takes time to change the rotating speed after changing the drive electric current.

The rotating change time can be made short if the change of the drive electric current makes big. However, when the change of the drive electric current is too big, the rotating speed cannot be made constant. Speed reference value is adjusted at the value to set to speed. Control rate value is adjusted at the value to set to Capture, Compare and Pulse Width Modulation Registers (CCPR2H and CCPR2L). When the control rate value is big, the rotating speed of the motor changes big.

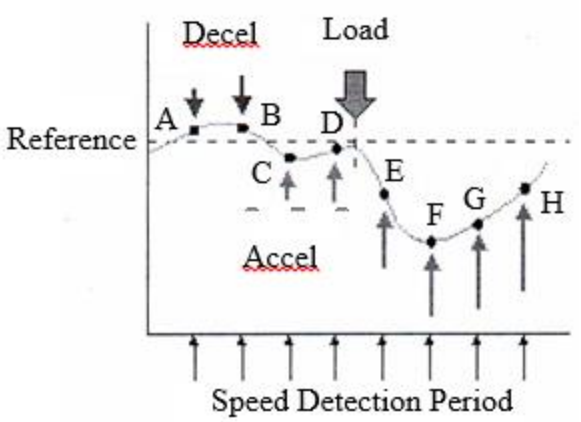

Figure 1 : Illustration of Speed Control Parameters

When the rotating speed of the motor is above the reference value, a deceleration control is done (i.e, it reduces a drive electric current). However, because of the mass of the rotor of the motor, it doesn't react immediately. Even if it begins deceleration by the point A, the rotating speed of the motor continues to rise in a little while. In case of the point B is above the reference value, a deceleration control is done moreover. In case the speed is above the reference value, the drive electric current is increased in every period. The deceleration value at point B is bigger than point A. Therefore, it continues to decelerate even if it falls below the reference value.

When detecting rotating speed is below the reference value in the point C, acceleration is begun. It is more strongly accelerated every period like the deceleration. It repeats above mentioned operation and the rotating speed of the motor changes widely.

In case of the control circuit, it increases a declaration value or an acceleration value every period. Even if a control electric current is changed, the rotating speed doesn't sometimes change immediately. This is because of the mass of the rotor. When the speed detection period is short, the motor drive electric current changes widely. As a result, the change of the rotating speed becomes big. When the speed detection period is long, the motor drive electric current changes small. As a result, the change of the rotating speed becomes small [4].

II. HARDWARE AND SOFTWARE OVERVIEW

The functional block diagram of the DC motor speed controller is shown in Figure 2. In Figure 2, microcomputer, A/D and pulse width modulation hardware are all integrated in the PIC16F873A microcontroller chip.

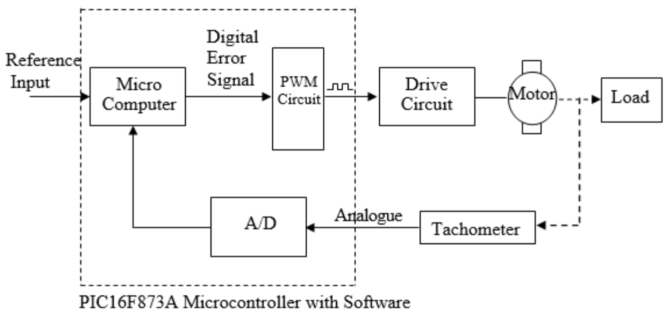

Figure 2 : Block Diagram of the DC Motor Speed Controller

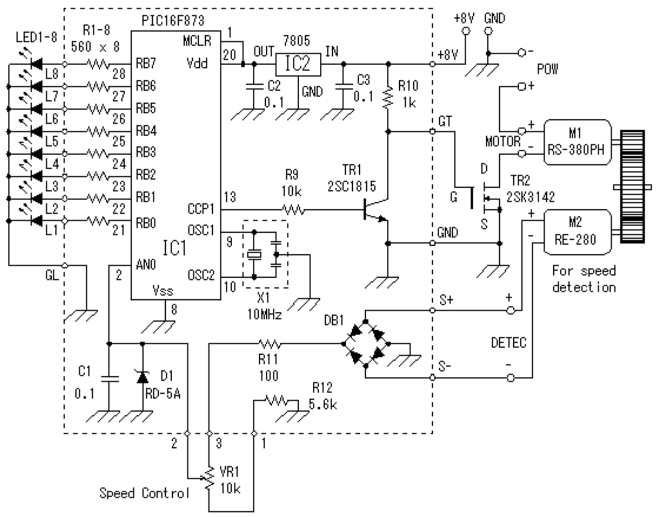

Figure 3 : Schematic Diagram for DC Motor Speed Controller

The complete schematic circuit diagram of DC motor speed controller is shown in Figure 3. General anatomy of the firmware program is shown in Figure 4.

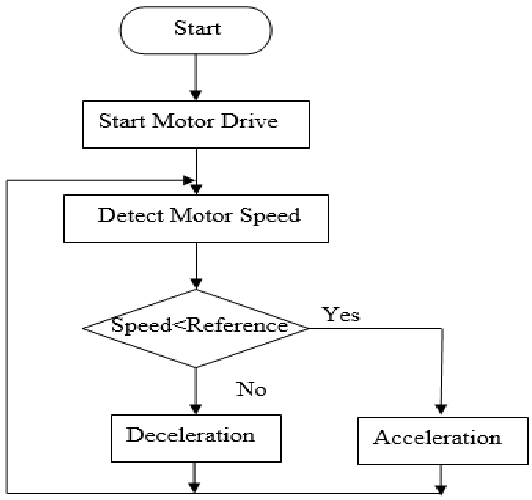

Figure 4 : Overall Block Diagram of DC Motor Speed Controller

2.1 Hardware Description for DC Motor Speed Controller

The hardware circuit of Figure 3 can be subdivided into four sections:

(i) Control voltage input circuit or feedback circuit
(ii) Motor drive circuit
(iii) LED bar graph display
(iv) PIC16F873A with support circuitry.

2.1.1 Control Voltage Input Circuit

Control voltage input circuit or feedback circuit section is illustrated in Figure 5. The heart of feedback circuit is the small motor M2 which operate as a generator to detect the number of rotations of the motor.

In other words, M2 operates as a tachometer since M2 and main motor M1 are mechanically coupled with a plastic gear assembly. Output voltage produced by the tachometer M2 is directly proportional to the rotational speed of the main motor M1. Polarity of this output voltage, which has to be applied to the A/D input, depends on the direction of rotation of the main motor M1. Since the A/D has been configured to handle the positive unipolar input voltage with respect to ground, bridge rectifier DB1 is used to maintain the feedback voltage always positive regardless of the direction of rotation of the main motor M1. The purpose of the 5 V zener diode D_1 is to protect the electronics components, (PIC microcontroller and on chip A/D, etc.) from the harsh environment in which the main and detection motors are operating in. This sample over voltage protection circuit ensures that the feedback voltage won't exceed 5 V and damage the microcontroller. 0.01 μF capacitor C_1 is used as a high frequency decoupling capacitor.

The voltage divider network, composed of R_{11}, R_{12} and 10-turn potentiometer VR_1 is adjusted by VR_1 for the desired amount of feedback voltage over the operating speed range of the motor. The objective is the desired speed command can be provided to the microcontroller by adjusting the amount of feedback voltage via VR_1. Since the reference speed value used is the firmware program is a constant, small amount of feedback corresponds to the high speed of rotation of the motor. R_{11} and R_{12} are used as end stop resistors which limits the lower and upper end of the rotational speed which can effectively control by the DC motor speed controller.

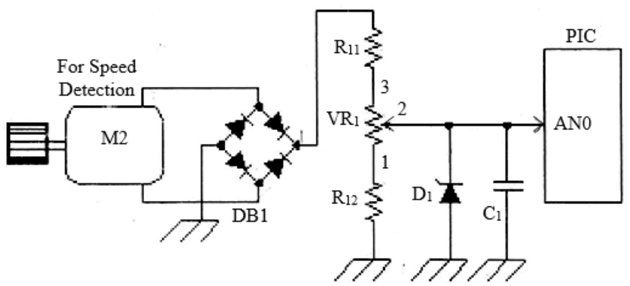

Figure 5: Control Voltage Input Circuit

2.1.2 Motor Drive Circuit

Equivalent circuit for the motor drive circuit and corresponding voltage waveforms at some critical points are illustrated in Figure 6. In this diagram +V is motor supply voltage and +8 V is the power supply voltage for the electronic circuits. N channel MOSFET transistor TR2 is the driver transistor and since it is connected between the motor and the circuit ground the small duty cycle of the voltage waveform at drain terminal of the MOSFET TR2 results is a high rotational speed of the motor and vice versa. Bipolar transistor TR1 acts as an inverter to the input of the gate of TR2 and it also function as a level shifting transistor for providing the gate of TR2 with enough voltage to conduct.

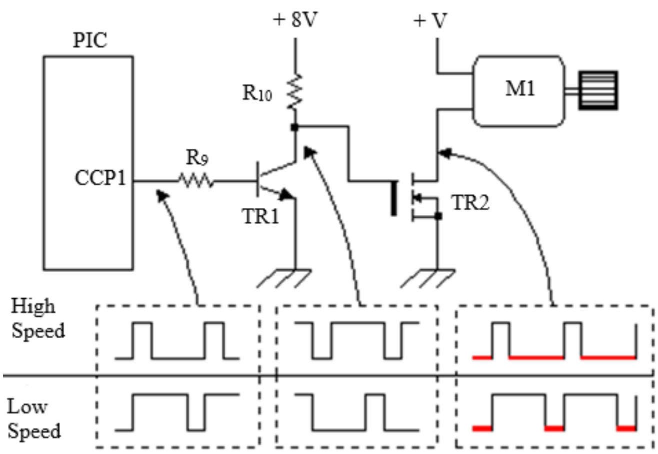

Figure 6 : Motor Drive Circuit

By investigating the voltage waveforms at critical points, CCP1 pin of PIC microcontroller, collector of TR1 and drain terminal of TR2, it is obvious that small duty cycle of the output voltage at CCP1 pin will drive the motor with high rotational speed and the large duty cycle output voltage waveforms at CCP1 pin will drive the motor with low rotational speed.

2.1.3 LED Bar Graph Display

The LEDs shown in the schematic diagram of Figure 7 are used to implement a bar graph display used by the firmware to indicate the rotation speed of the motor. This is one rotational of the most popular types of multi-LED indicator circuits known as analogue value indicator or graph display, which is designed to drive a chain of linearly-spaced LEDs in such a way that the length of chain that is illuminated is proportional to the analogue or digital value of a voltage applied to the input of the LED-driver circuit, e.g., so that the circuit acts like an analogue voltmeter. In this research, digital value applied to the input sections of the LED driver circuit is proportional to the rotational speed of the motor, looking much the same as a LED-bar group display on modern audio equipment. Practical graph circuits may be designed to generate either a bar-graph display or a dot display value is indicated by the total number of LEDs that are illuminated. In the dot display the input value is indicated by the relative position of a single illuminated LED. In this research eight-LED bar graph display is used to display the rotational speed of the motor [2].

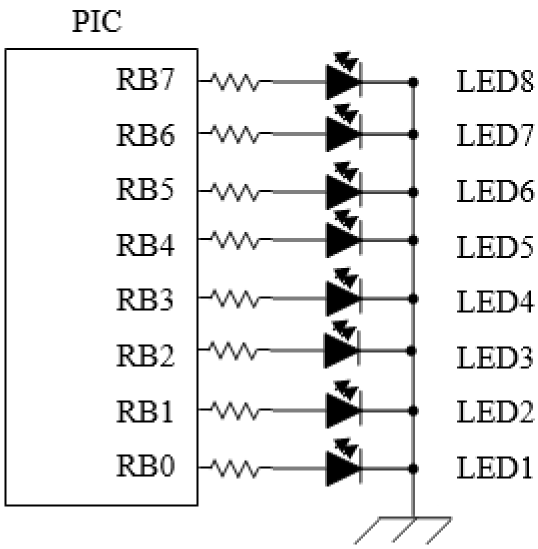

Figure 7: LED Displaying Circuit

2.1.4 PIC16F873A Microcontroller with Support Circuitry

The heart of the DC motor speed controller is the PIC16F873A microcontroller. A typical system for a control of a DC motor includes an A/D, microcomputer and pulse width modulator that performs the signal processing algorithm as shown in Figure 2. The PIC16F873A with its on-chip A/D, PWM module, and fast control processing unit (CPU) is an ideal candidate for use in DC motor speed control system of Figure 1. Support circuitries of PIC microcontroller are power supply circuit, oscillator circuit and power-on reset circuit.

Power supply circuit for microcontroller is constructed by using an fixed voltage regulator IC 7805, IC2 as shown in Figure 3.The 7805 is a three terminal device and can provide up to 1 A and output voltage of 5 V. The 0.1 µF capacitors C2 and C3 are used for stability and improved transient response.

The heart of the PIC16F873A is the circuitry that generates the clock pulse by which all internal operations are synchronized. Pins OSC1 and OSC2 are provided for connecting a network to form an oscillator. Typically, a quartz crystal and capacitors are employed. A 10 MHz crystal, X1 and two 10 pF capacitors are used in Figure 8.

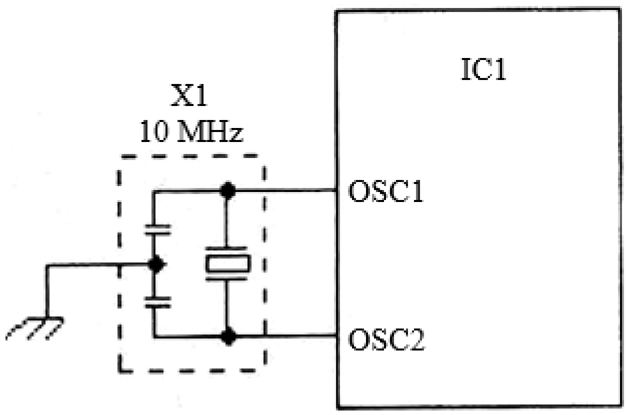

Figure 8: Clock Generator Circuit

A power-on reset pulse is generated on chip when power supply voltage V_{DD} rise is detected. To take advantage of the power-on reset, the master clear pin ($\overline{MCLR}$) pin is directly connected to V_{DD} as shown in Figure 3.

2.2 Software Implementation of DC Motor Speed Controller

The software (source code) for the DC motor speed controller was written using MPASM assembler. The MPASM assembler provides an Integrated Development Environment and generates highly optimized code for the entire PICmicro family.

The entire motor speed control function is implemented by using the algorithm as illustrated in Figure 3, which must perform the following tasks:

(i) Get current motor speed,
(ii) Get desired motor speed,
(iii) Find the speed error and
(iv) Determine new PWM duty cycle.

Timer 1, the time base for the CCP1 module, is used to generate interrupts. That time the sampling processing to determine the current motor speed. The overall motor speed controller software contains two parts:

(i) Initialization process,
(ii) Interrupt service routine.

Flow charts for the Initialization process and Interrupt service routine are shown in Figure 4.8 and 4.9. The source code (DC. Motor.asm) in assembly language in Appendix shows how to implement DC motor speed control function.

2.2.1 Initialization Process

The initialization routine is executed only once at the start of the program. The Interrupt service routine is executed every 10 ms. The Initialization routine does the following:

(i) Configures PORTA bit 0 as analogue input, PORTB as output port for LED control and PORTC as output port for PWM output,
(ii) Configures A/D converter,
(iii) Configures CCP1 module as PWM mode. The period of pulse width modulation is set to 1638.4 μs about (610 Hz),
(iv) Configures CCP2 module as compare mode in Special Event Trigger mode to start A/D conversion every 10 ms when CCP interruption occurs,
(v) Enables interrupt and waits for interruption process.

2.2.2 Interrupt Service Routine

As previously explained the interruption occurs every 10 ms and start A/D conversion automatically. The Interrupt Service Routine does the following:

(i) Clears interrupt flag,
(ii) Waits for A/D conversion to complete,
(iii) If the A/D conversion completes, the converted result is compared with the reference speed value,
(iv) When the measured value is higher than the reference value duty cycle value of PWM is change to reduce the speed of rotation of motor. When the measured value is lower than the reference value PWM duty cycle value is adjusted to increase the speed of motor and
(v) The LED bar graph display is updated by the data corresponding to current motor speed value and return from the interrupt routine [11].

III. RESULTS AND DISCUSSIONS

The performance of the constructed DC motor control circuit is tested under wide range of motor supply voltages and load conditions. It is also tested under wide range of speed command values and it proves to operate as intended. It can be concluded that the present hardware and software techniques proves to be a very inexpensive and efficient way to control the speed of a small DC motors which can be used in robotic application.

In the early stage of design and development cycle of the present research work, the performance of the system is tested under various sampling interval values and it is found that the optimal value is 10 ms and it is used in the final design.

The frequency of PWM signal that drives the motor should be high enough so that a minimal amount of current ripple is induced in the windings of the DC motor. The amount of current ripple can be derived from the PWM frequency, motor winding resistance, and motor inductance. An important consideration when choosing PWM frequency for a motor control application is the responsiveness of the motor to changes in duty cycle. A motor will have a faster response to change in duty cycle at higher frequencies.

Another important consideration is the sound generated by the motor. Brushed DC motors will make an annoying whine when driving at frequencies within the audible frequency range (20 Hz to 4 kHz.). In order to eliminate this whine, brushed DC motors are used to operate frequencies greater than 4 kHz. (Humans can hear frequencies at upwards of 20 kHz, however, the mechanics of the motor winding will typically attenuate motor whine above 4 kHz). PWM frequency used in this research is only 160 Hz and it is very much lower than 4 kHz, and an annoying sound is produced by the motor. So it was tried to eliminate this by increasing the PWM frequency. But it is found that the motor driver FET used in this research cannot operate properly at high frequencies. It may be the general purpose device. A high frequency switching FET has to be used to operate at higher frequencies [12].

IV. FURTHER EXTENSION

The present research work shows how a mid-range PIC microcontroller can be used to efficiently control the speed of a small DC motor with minimum hardware requirements. Direction of rotation of the motor used in this research is in only one direction (it is unidirectional). For some applications that used a DC motor requires it to reverse its direction as well as to vary its speed. The present hardware and software can be modified to control both the direction and speed of rotation of a DC motor. Both the position and velocity motion control system can be implemented with the present system by modifying the both hardware and software. Additional hardware components such as position sensor and the software components such as PID (proportional, integral, differential) algorithm have to be used in the design.

In the present design the microcontroller receives its control information from the user via manually control voltage divider network. PIC16F873A and other midrange devices have two on chip built in serial peripheral communication modules: Synchronous Serial Port (SSP) module and Universal Synchronous and Asynchronous Receiver Transmitter (USART) module. By using one of these modules the present design can be configured to make serial communication link with a host computer (such as a Personal Computer (PC) or another microcontroller system). In this way the system can receive its command and control information from the host via the serial bus. In this way this system can be modified to a remote intelligent controller which can be used to control any proportional DC actuator (i.e., DC motor or proportional valve). Another possibility is that, since any serial communication method is applicable, it can be configure to receive command via radio frequency (RF) or Infra-Red (IR) medium.

V. CONCLUSION

The research work is just the first step to construct microcontroller-based motor control system which can be used in small robotic applications. Even though the achievement of the research work is relatively simple it is a major accomplishment for doing future work in this field. Besides, the knowledge and the experience gained from the research work would be a great help for further development in the field of microcontroller and its application.

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