ENGR 323L: Embedded System Design
Department of Engineering, Trinity College
Instructor: Professor Taikang Ning

Laboratory Project: DC motor speed control using pulse width modulation (PWM)

Lab Description:

This design laboratory is to help students learn and become familiar with designing and implementing a DC motor speed control embedded system, which involves Pulse-Width Modulation (PWM) and PID controller design. PWM allows manipulation of the duty cycle to alter the rotating speed of DC motors per varying shaft-load. The design goal of this lab is to use the SiliconLab-C8051F120 kit to implement a PID controller that allows the user to enter the desired target speed. With feedback, the PID controller can make timely adjustment of the driving current to accommodate the changing shaft-load to maintain the desired rotating speed. A system block diagram is given in Fig.1.

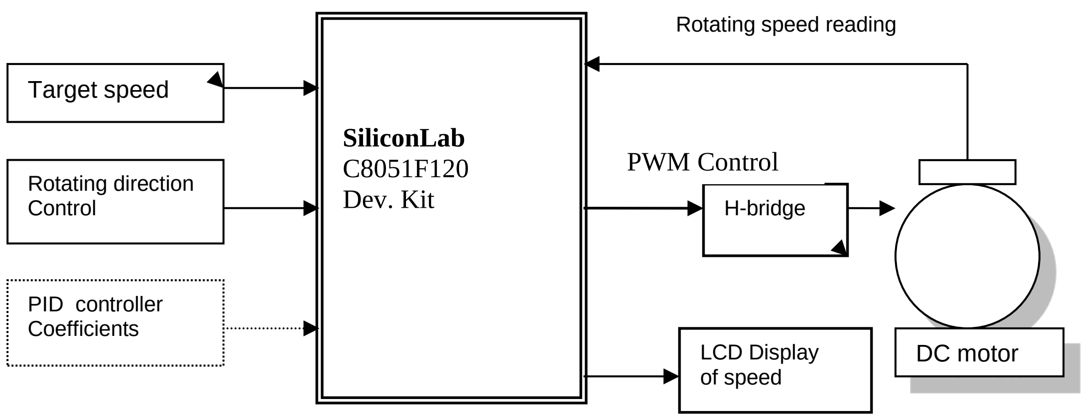

Figure 1: System configuration of DC motor speed control

The DC motor controller needs to satisfy the following design specifications:

- users can easily change the desired motor speed within a pre
- determined range (depending on the power supply and the loading condition, the DC motor may or may not achieve the target speed)
- PWM signal is used to control DC motor speed
- use push button(s) to control the rotating direction
- adjustable feedback controller (e.g., the PID controller)
- display system information, e.g., desired speed and actual speed of the DC motor, using a 16x2 LCD

Pulse-width modulation (PWM) – PWM can be adopted in many applications. One typical use of PWM is to vary the average voltage through a digital output. By manipulating the *duty cycle*—the percentage of time when the output is "*on/high*" during one period, PWM can control the average output voltage value between *0* and the *source voltage*. In this lab, the SiliconLab-C8051F120 will be the used to generate the appropriate PWM signal to control motor rotation speed. The PWM output can be connected directly to an intelligent PWM control H-Bridge chip that will translate the duty cycle information to drive the DC motor accordingly. To maintain the same motor speed when load varies, a stable feedback control system must be designed and employed to provide acceptable speed control.

DC Motor Rotating Speed Measurement and Control

The speed of a DC motor can be measured by a tachometer —a small electric generator that consists of a coil mounted in a magnetic field and, when the coil rotates, an alternating electromagnetic field is induced in the coil and the magnitude of the maximum *e.m.f.* which can be used as a measure of the angular velocity. The DC motor speed also can be monitored using an optical encoder, consisting of a slotted disk and a phototransistor-LED pair. The sensor outputs a pulse whenever the slot in the disk passes by the phototransistor-LED pair. Therefore, the rotating speed of the motor can be estimated by the by the frequency of the pulse signal. A schematic of the encoder is shown in Fig.2.

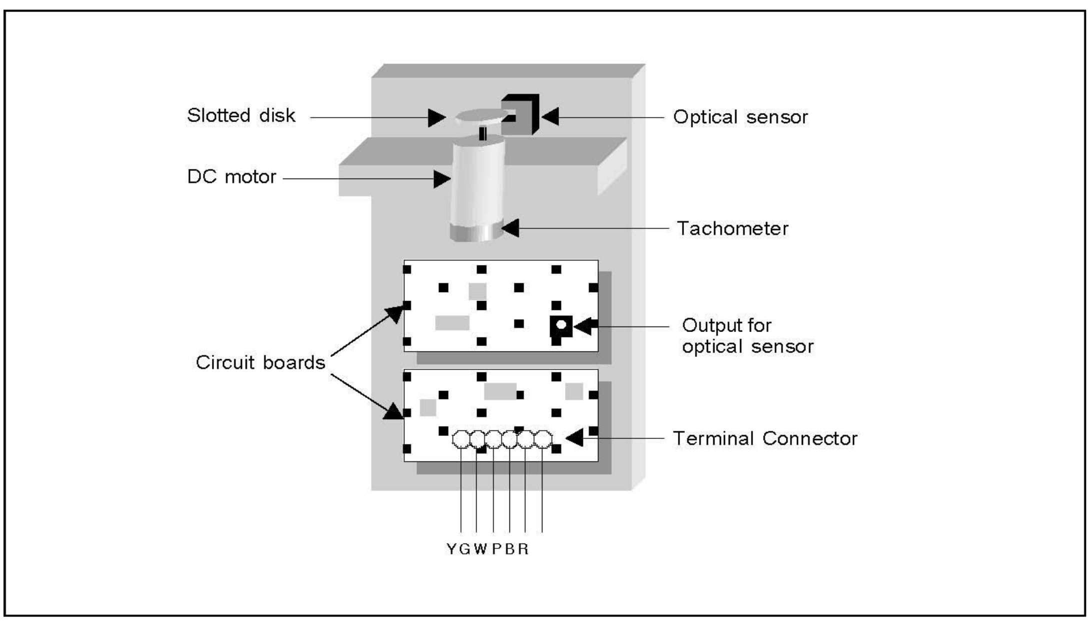

Figure 2: Optical encoder of a DC motor

DC motor with a built-in optical encoder — The DC motor used for this lab is rated at 9 VDC with a maximum continuous torque of 3.32oz-in and maximum continuous current of 1.5 amps with approx. 1.5 oz-in load. For normal operating condition, the motor spins at 3000 rpm and drains a current of approximately 650 mA. Note that the DC motor may not be able to maintain the desired speed for a heavy load with insufficient power supply. Recommended diode current 30 mA. Maximum recommended phototransistor current is 5 mA.

A built-in optical encoder uses a phototransistor/LED sensor pair (powered by 5 volts with a maximum recommended phototransistor current of 5 mA) will generate a sinusoidal signal with 80 counts per turn with 0.2-2 volts peak-to-peak. To interface this encoder with 8051 properly, a signal conditioning circuit is necessary to convert the small-amplitude sine waves produced by the optical encoder to pulses recognized by the microcontroller. For this reason, a comparator circuit can be used to detect and remove non-zero DC offset voltage of the signal. Analog comparators compare two analog voltages where one input is typically a reference voltage and the other the unknown value. When the unknown voltage exceeds the reference, the output of the comparator switches from one binary state to another. A DC-level detection comparator circuit can be easily built using 741 op-amp shown below on the left. You can use an oscilloscope to measure the sine waves from the DC motor and determine an appropriate reference voltage for detection and the output of the comparator shown below on the right.

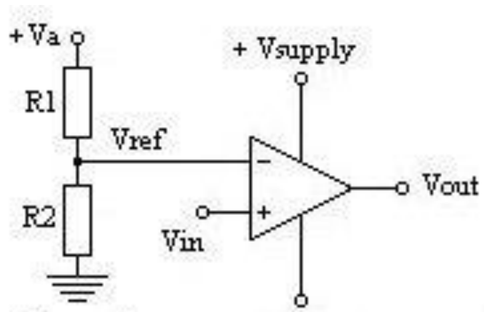

Figure 1

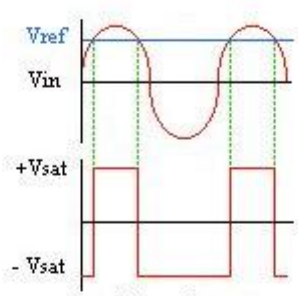

Figure 2

DC Motor Rotating Speed (rpm):

rpm = $total\_pulse\_count * \frac{1\sec}{xm\sec} * \frac{1turn}{80counts} * \frac{60\sec}{1\min}$

Where $total\_pulse\_count$ is the total number of pulses measured in x-msec.

H-Bridge is an IC chip that converts digital pulses of varying duty cycle and output a DC voltage because the PWM signal is with insufficient output current to drive a motor which needs a relatively higher power to make rotation, i.e., the speed of a motor can be controlled by the duty cycle of the PWM signal. A commonly used h-bridge chip (SN754410) is shown in Fig.3. The SN754410 is a quadruple high-current half-H driver designed to provide bidirectional drive currents up to 1 A at voltages from 4.5 V to 36 V. Pins 1A and 2A are direction controls. The Enable lines (1,2EN, 3,4EN) must be set high to enable power to the motor.

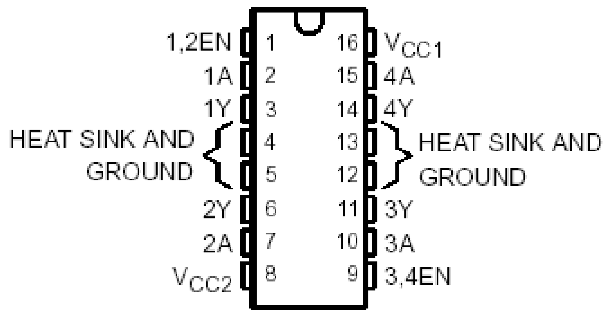

Figure 3: H-bridge (SN754410)

The DC motor used in the lab design project has six connection wires: Motor+, Motor-, Emitter, Collector, Cathode, and Anode.

- Emitter and Cathode connect to ground
- Collector connects to a voltage source of 5V through a resistor (e.g., 1-1.5 kΩ) to generate an appropriate current for the phototransistor (*note the max is 5 mA*).
- Anode connects to a voltage source of 5 V through a resistor (e.g., 200 – 300 Ω) so that about 27 mA of current is allowed to flow, which is below the maximum recommended diode current
- Motor+ and Motor- connect to outputs (1Y and Y2) of the H-bridge chip (SN754410), respectively.

Feedback Controller – A feedback controller is necessary to adjust the PWM signal to achieve a desired target speed (set point). The most commonly used is the proportional, integral and derivative (PID) controller. A PID controller when tuned properly can be used to obtain a very good control over the output. It can make the output response follow the input more closely with small overshoot or undershoot, little oscillation and fast response time. Users need to determine three coefficients (K_P, K_I and K_D). To test for performance, one can start by attaching a light load to the shaft with a desired speed at 50% duty cycle. Then, by removing the load or increasing the load, the duty cycle should be automatically adjusted accordingly by the controller to maintain the desired speed. How long it takes to swing back to the set point with varying load reflects the quality of the controller. A good control system also allows easy adjustment of PID controller coefficients. A block diagram design of a DC motor speed control system is exemplified in Fig.4.

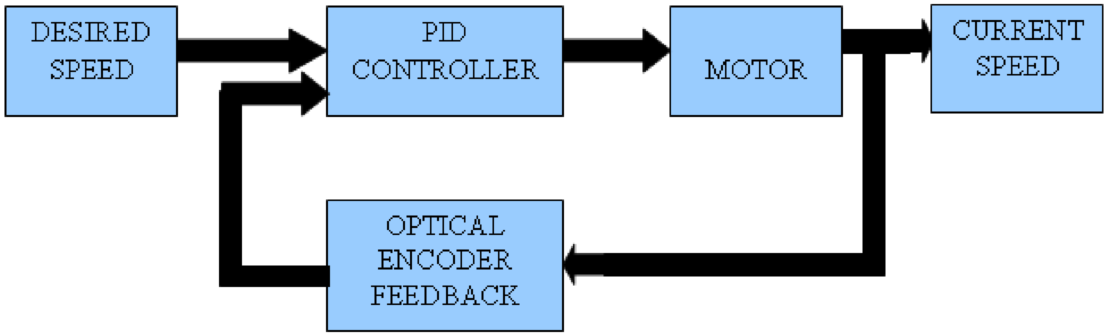

Figure 4: Block diagram of a DC motor control system