DC Motors and Encoders
DC Motors

• The DC motor has a permanent magnetic field and its armature is a coil

• When a voltage and a subsequent current flow are applied to the armature, the motor begins to spin

• The larger the current through the coil, the larger is the force (and torque)

• Reversing the direction is done by changing the polarity of voltage applied to the motor
Pulsed Width Modulation (PWM)

- To control the speed of the motor we need to vary the input voltage to the motor.

- However, it’s difficult to output a variable voltage from a microcontroller.

- Instead, we can change the average value of the output voltage by rapidly turning the output on and off using a square wave.

- “Duty cycle” is the ratio of the “on” time to the period of the wave.

- The PWM switching frequency has to be much faster than what would affect the load.

- For a motor, it should be a few kilohertz (kHz) to tens of kHz.
Using MCU to Generate a PWM

- Example: generate a PWM whose duty cycle is proportional to an input voltage signal
  - I.e., when
    - Vin=0V, the value of duty = 0 (0%)
    - Vin=5V, the value of duty = period (100%)
  - Period is fixed
  - This is a “voltage-to-duty cycle” converter (in Lab 4 you did a “voltage-to-frequency” converter)

- Pseudo code

  Initialize output
  Initialize period to some constant value
  while (true) do
    Digitize input voltage, convert to a duty value
    Turn on output
    Delay for the time corresponding to duty
    Turn off output
    Delay for time corresponding to period minus duty
  end while
H-bridge

- A circuit that enables a voltage to be applied across a load in either direction
- By closing two of the switches at a time, you can run the motor forwards or backwards
- If all switches are open, the motor is “freewheeling”
- If say, S2 and S4 are closed and S1 and S3 are open, the motor is “braking”
- Note – you would never want to close say, S1 and S2 simultaneously!

The switches are typically high power transistors

Structure of an H bridge, highlighted in red (from wikipedia)

The two basic states of an H bridge (from wikipedia)
H-bridge driver

- H-bridge drivers are available as a single integrated circuit
- Example: TLE 5206 on the SSMI board

- To make it easier to use (and avoid the possibility of accidentally turning on the wrong pair!) there are only two inputs (IN1, IN2)

- Choices:
  - Forward: IN1=0, IN2=1
  - Reverse: IN1=1, IN2=0
  - Freewheel: IN1=0, IN2=0 (or both equal to 1)
PWM Control

• To run motor forwards:
  – Make IN1=0 and do PWM on IN2

• To run motor in reverse:
  – Make IN2=0 and do PWM on IN1

  In both cases
  – Speed is proportional to duty
  – Period is constant
Sensing Position and Speed

• A *rotary encoder* is a sensor that converts the angular position or motion of a shaft or axle to an analog or digital signal

• Applications:
  – Sensing the state of computer mice and trackballs
  – Feedback control of motors (velocity and position)

• Encoders can be digital or analog

Hall-effect quadrature encoder, sensing gear teeth on the driveshaft of a robot vehicle (http://en.wikipedia.org/wiki/Rotary_encoder)
Digital encoder technologies

• Magnetic
  – Based on the “Hall effect”
  – A voltage difference is produced across an electrical conductor, transverse to the current through the conductor and a magnetic field perpendicular to the current

• Optical
  – A light shines onto a photodiode through slits in a disc
  – Or, light is reflected off markings or teeth, and detected by a photodiode

The voltage from the sensor will peak twice for each revolution (this can be converted to a digital signal). From http://en.wikipedia.org/wiki/Hall_effect_sensor
Optical encoders

- A single sensor, used with a single pattern track, can only measure angular velocity
- Multiple sensors, used with multiple tracks, can measure angular position

Rotary encoder for angle-measuring devices marked in 3-bit binary-reflected Gray code BRGC)

From http://en.wikipedia.org/wiki/Rotary_encoder

<table>
<thead>
<tr>
<th>Sector</th>
<th>Contact 1</th>
<th>Contact 2</th>
<th>Contact 3</th>
<th>Angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>off</td>
<td>off</td>
<td>off</td>
<td>0° to 45°</td>
</tr>
<tr>
<td>1</td>
<td>off</td>
<td>off</td>
<td>ON</td>
<td>45° to 90°</td>
</tr>
<tr>
<td>2</td>
<td>off</td>
<td>ON</td>
<td>ON</td>
<td>90° to 135°</td>
</tr>
<tr>
<td>3</td>
<td>off</td>
<td>ON</td>
<td>off</td>
<td>135° to 180°</td>
</tr>
<tr>
<td>4</td>
<td>ON</td>
<td>ON</td>
<td>off</td>
<td>180° to 225°</td>
</tr>
<tr>
<td>5</td>
<td>ON</td>
<td>ON</td>
<td>ON</td>
<td>225° to 270°</td>
</tr>
<tr>
<td>6</td>
<td>ON</td>
<td>off</td>
<td>ON</td>
<td>270° to 315°</td>
</tr>
<tr>
<td>7</td>
<td>ON</td>
<td>off</td>
<td>off</td>
<td>315° to 360°</td>
</tr>
</tbody>
</table>

Quadrature encoders

- Two sensors can measure velocity and direction

- Two square waves (A and B) are produced, 90° out of phase
  - If A leads B, the disk is rotating in a clockwise direction
  - If B leads A, then the disk is rotating in a counter-clockwise direction
Quadrature encoders

- Depending on the direction of rotation you will get either:
  - 00 = 0
  - 01 = 1
  - 11 = 3
  - 10 = 2

- or
  - 00 = 0
  - 10 = 2
  - 11 = 3
  - 01 = 1

- So we can estimate the direction of motion with the table shown

- Or, if you don’t care about direction you can just use one of the sensors to measure velocity (or combine the two for twice the precision)

http://letsmakerobots.com/node/24031
Example

- Encoder for toy wheel
  - Uses two infrared reflectance sensors
  - Positioned inside the hub of a wheel
  - Measures the twelve teeth along the wheel

http://www.pololu.com/catalog/product/1217
Summary / Questions

• Why shouldn’t you drive a DC motor directly from a microcontroller output pin?

• Pulse width modulation (PWM) is used to vary the power going to a motor, since microcontrollers only have digital output pins. How can you pick the period of the PWM?

• How can you use a quadrature encoder to sense the direction of rotation?