Controlling a Brushless Motor
Parts: Layout and Fabrication

Finish your design and fabrication of parts this week:

- a base plate that supports a motor shaft,
- 1+ electromagnets attached to the base plate to form the stator,
- 1+ Hall-effect sensors attached to the base plate, and
- a rotor with 1+ permanent magnets.

Fabrication tips:

- Laser cut acrylic (1/4”, 1/8”, and/or 1/16”) for planar parts.
- 3D print non-planar parts (but note that 3D printing is slow).
- Our power supplies provide 5V to drive electromagnets
  - limit power to 2 watts per electromagnet to avoid overheating
  - use 32 gauge wire for simple designs with plastic bobbins
- Use **screws** to hold pieces together – **NO glue or tape**
Controlling a Brushless Motor: Example
Using Hall-Effect to Sensor Rotor Angle

![Diagram showing rotor angle (degrees) and sensor positions.](image)
Using Hall-Effect to Sensor Rotor Angle

- Sensors
- Rotor angle (degrees)

- 30
- 60
- 90
- 120
- 150
- 180
- 210
- 240
- 270
- 300
- 330
- 360
Using Hall-Effect to Sensor Rotor Angle

![Diagram showing a rotor with Hall-Effect sensors and a graph indicating rotor angle (degrees).]
Using Hall-Effect to Sensor Rotor Angle

The diagram illustrates the use of Hall-Effect sensors to measure the rotor angle. The sensors are placed at specific points around the rotor, and the graph shows how they respond to the rotor's rotation. The rotor angle is measured in degrees, and the sensors are marked at intervals of 30 degrees, from 30 to 360 degrees clockwise.
Using Hall-Effect to Sensor Rotor Angle

The diagram illustrates the use of Hall-Effect sensors to measure the rotor angle. The sensors are aligned in a clockwise direction, and their responses are plotted against the rotor angle in degrees. The rotor angle is indicated along the horizontal axis, ranging from 30 to 360 degrees, while the vertical axis represents the sensors' output.
Using Hall-Effect to Sensor Rotor Angle

- Diagram showing a rotor with sensors marked NS, indicating the positions of the sensors.
- A graph showing the rotor angle in degrees from 0 to 360 degrees, with sensor positions marked at specific intervals (30, 60, 90, 120, 150, 180, 210, 240, 270, 300, 330, 360 degrees).
- The graph indicates a sensor position at 150 degrees.
Using Hall-Effect to Sensor Rotor Angle

![Diagram showing sensors and rotor angle graph]
If A senses no field, the angle could be 0 or 60 degrees. Add a second sensor to distinguish.
Using Hall-Effect to Sensor Rotor Angle

- **sensors**
- **rotor angle (degrees)**

Diagram showing the relationship between sensors and rotor angle.
Using Hall-Effect to Sensor Rotor Angle

![Diagram showing sensor positions and rotor angle](image-url)
Using Hall-Effect to Sensor Rotor Angle

[Diagram showing a rotor with南北NS NS NS NS NS NS and sensors marked clockwise.

Graph with rotor angle (degrees) on the x-axis and sensors on the y-axis, indicating the magnetic field changes as the rotor turns.]
Using Hall-Effect to Sensor Rotor Angle

![Diagram showing Hall-Effect sensor placement and rotor angle in degrees. The diagram includes a circular rotor with north and south poles and corresponding sensors. The graph below the diagram displays sensor readings over a range of rotor angles from 30 to 360 degrees.]
Using Hall-Effect to Sensor Rotor Angle

- Rotor angle (degrees):
  - 30
  - 60
  - 90
  - 120
  - 150
  - 180
  - 210
  - 240
  - 270
  - 300
  - 330
  - 360

- Sensors
- Clockwise
Using Hall-Effect to Sensor Rotor Angle

Three identical cycles per turn (three-fold symmetry of rotor). Sensor outputs identify unique angle within each cycle.
Characterizing Torque

clockwise torque

rotor angle (degrees)
Characterizing Torque

clockwise torque

rotor angle (degrees)
Characterizing Torque

Clockwise torque vs. rotor angle (degrees)

- 30°, 60°, 90°, 120°, 150°, 180°, 210°, 240°, 270°, 300°, 330°, 360°
- Torque varies periodically with rotor angle.
Characterizing Torque

The diagram shows the relationship between the clockwise torque and the rotor angle. The rotor angle is marked in degrees, with values ranging from 30 to 360 degrees. The clockwise torque is depicted by the red line, which varies periodically with the rotor angle.
Characterizing Torque

Torque vs. Rotor Angle (degrees)

Clockwise torque

Rotor angle (degrees)
Characterizing Torque

The diagram illustrates the relationship between clockwise torque and rotor angle (degrees). The torque peaks at specific rotor angles, indicating the effect of electromagnetic interaction on the motor's performance. The clockwise torque is plotted against the rotor angle, showing a sinusoidal pattern with peaks at every 120 degrees.
Characterizing Torque

[Diagram showing a rotor with magnetic poles and a graph plotting clockwise torque against rotor angle (degrees).]
No torque is produced at multiples of 60 degrees.
Add a second set of electromagnets.
Characterizing Torque

[Diagram showing a circular representation with N and S poles at various angular positions, indicating the relationship between rotor angle and clockwise torque.]
Characterizing Torque

![Graph showing torque across rotor angle (degrees)](image)

- Clockwise torque values are indicated on the graph.
- The rotor angle (degrees) is shown on the x-axis.
- The y-axis represents clockwise torque.

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N S N S N S N S

30 60 90 120 150 180 210 240 270 300 330 360

rotor angle (degrees)
Characterizing Torque

Rotor angle (degrees)

Clockwise torque

30 60 90 120 150 180 210 240 270 300 330 360

rotor angle (degrees)
Characterizing Torque

clockwise torque

rotor angle (degrees)

30 60 90 120 150 180 210 240 270 300 330 360
Characterizing Torque

clockwise torque

rotor angle (degrees)
Characterizing Torque

clockwise torque

rotor angle (degrees)

30 60 90 120 150 180 210 240 270 300 330 360
Characterizing Torque

clockwise torque

rotor angle (degrees)
Characterizing Torque

clockwise torque

rotor angle (degrees)
Mapping Sensor Readings and Torque Versus Angle

clockwise torque

sensors

rotor angle (degrees)

rotor angle (degrees)
Teensy 3.2 Microcontroller

The Teensy3.2 is a powerful and inexpensive controller.


Four dedicated pins:
- two power pins: power in (5V) and power out (3V, 0.1A max)
- two grounds: analog and digital.

24 programmable pins:
- any of these can be used for digital in/out
- 10 pins (A0-A9) can be used for analog in/out
Switches for Electromagnets

Adafruit TB6612 board: 2 H-bridges to control electromagnets.

Each H-bridge can supply up to 1.2A at 5V to one or multiple coils
- connected in parallel (so that currents add) or
- connected in series (so that voltage is divided among them).
External Power Supply

Power for motors is provided from an external microUSB connector.

To use the same source for Teensy (so that motor can run without a laptop) we must disconnect power from the Teeny’s USB port.

Then power comes from external microUSB connector, and USB connector on the Teensy is only used to control the Teensy.
Wiring

Solder wire-wrap connectors to Teensy, TB6612, and USB boards.

Use wire-wrap to connect power and ground leads as follows.

![Diagram showing connections between Teensy, TB6612, and USB boards]
Test Power Wiring

Test power connectors to avoid damage to your laptop or circuits.

**Step 1:** Plug USB power supply into Teensy USB connector and then into wall power. Since we cut the USB power supply, the integrated led shown below should **NOT** blink. If it does, recut the power trace on the backside of the Teensy and repeat this test.

![led blinker]

**Step 2:** Remove USB power supply from Teensy USB connector and plug it into the microUSB board. Now the integrated led should **blink**. If it does not, then power is not getting to the Teensy from the microUSB board. Check your power connectors and repeat test.

Do not proceed until you get no blink in step 1 and blink in step 2.
Connecting Hall-effect sensors

Connect Hall-effect sensors.

- **left pin (red):** +3.3V
- **center pin (black):** gnd
- **right pin (blue):** one of Teensy’s analog pins (A0 to A9)

Multiple sensors can share +3.3V and gnd, but each must have a separate analog pin.
Connecting Electromagnets

Each TB6612 board has two H-bridges.

Multiple electromagnets can share the same H-bridge if they are always switched on and off at the same time.

- If connected in series, the voltage across each coil will be halved.
- If connected in parallel, the total current required will double.

Voltage from H-bridge $= 5V$.
Maximum current from each H-bridge is 1.2A.
Controlling an H-Bridge

Switches in each H-bridge are controlled by input pins: IN1 and IN2.

<table>
<thead>
<tr>
<th>Mode</th>
<th>IN1</th>
<th>IN2</th>
</tr>
</thead>
<tbody>
<tr>
<td>OFF</td>
<td>L</td>
<td>L</td>
</tr>
<tr>
<td>BRAKE</td>
<td>H</td>
<td>H</td>
</tr>
<tr>
<td>CW</td>
<td>H</td>
<td>L</td>
</tr>
<tr>
<td>CCW</td>
<td>L</td>
<td>H</td>
</tr>
</tbody>
</table>

H = high = +3.3V; L = low = gnd.

Unused inputs: PWM and STBY should be tied H.
Wiring an H-Bridge

Any of the Teensy pins 0 to 23 can be used as a digital control line.

Connect coils to TB6612 using wire-wrapped connections.

Use very fine sandpaper (600 grit) to remove the insulation from the last 2” of magnet wire. To prevent accidental short circuits, wrap 3” of magnet wire (1” with insulation and 2” without) so that ALL of the bare magnet wire is wrapped.
The Teensy 3.2 is compatible with Arduino. Use "Teensyduino" software. Installation is described at https://www.pjrc.com/teensy/td_download.html. Program examples are included in today's lab.