Motor Control
Questions?
Direct Current (DC) Motors

- Rotating shaft
- Fixed pair of magnets
Direct Current (DC) Motors

Wire placed within a magnetic field …
Direct Current (DC) Motors

Wire placed within a magnetic field:

• Force on the wire is perpendicular the magnetic field and to the direction of current through the wire

• Direction of force: determined by the left-hand rule
Direct Current (DC) Motors

- Force on the wire induces a torque about the motor shaft.
- Commutator switches direction of current every half cycle.
- Direction of torque remains the same throughout the cycle.
DC Motors

• Average motor torque is proportional to current flow through the wire
  – Wire has some resistance

• Direction of current flow determines torque direction

How can a digital input control torque magnitude?
DC Motors

How can a digital input control torque magnitude?

• Use Pulse Width Modulation (PWM)!

How do we handle torque direction?

Torque = force x lever arm
= (ILB) \frac{W}{2} \sin \theta \times 2 \text{ sides}
= ILBW \sin \theta = IBA \sin \theta
DC Motors

How do we handle torque direction?

- +3.3V to north 0V to south
- 0V to north +3.3V to south

How would we implement this with our microcontroller?
DC Motor Control

One possibility...

• Connect motor directly to the I/O pins

Two directions:
• PD2: 1; PD3: 0
• PD2: 0; PD3: 1
DC Motor Control

One possibility...

- Connect motor directly to the I/O pins

What is wrong with this implementation?
DC Motor Control

What is wrong with this implementation?

• Our I/O pins can source/sink at most 10 mA of current

• This is not very much when it comes to motors...

How do we fix this?
Base to emitter is a diode!

- Current from base to emitter is non-negative
- Small B->E current opens a “valve” that allows large C->E current
Transistors as Switches

(what we need to understand for our purposes)

Logic 0 (0V)

0 -> no current flow
Transistors as Switches

(what we need to understand for our purposes)

Logic 1 (5V)  

1 -> small amount of current flow from base to emitter
Transistors as Switches

(what we need to understand for our purposes)

1 -> small amount of current flow from base to emitter also allows (possibly large) current to flow from collector to emitter
Simple H-Bridge

+5V

[Diagram of a simple H-Bridge circuit]
Simple H-Bridge

What happens with these inputs?
Simple H-Bridge

What happens with these inputs?

- Motor turns in one direction
Simple H-Bridge

How about these inputs?
Simple H-Bridge

What happens with these inputs?

- Motor turns in the other direction!
Simple H-Bridge

How about these inputs?
Simple H-Bridge

What happens with these inputs?

• We short power to ground

... very bad
Simple H-Bridge

How can we prevent a processor from accidentally producing this case?
We introduce a little logic to ensure the short never occurs.

Modified H-Bridge

+5V
Modified H-Bridge

What happens with this input?
Modified H-Bridge

What happens with this input?
Modified H-Bridge

What happens with this input?

- Motor turns in one direction
Modified H-Bridge

How about this input?
Modified H-Bridge

What happens with this input?
Modified H-Bridge

How about this input?

- Motor turns in the other direction
This implementation is nice because we only need one **direction** bit of control

- What are we missing?
What are we missing?

• Control of torque magnitude
• Let’s introduce a second PWM input that turns the motor on/off
Pulse Width Modulation for Motor Control

Goal: given on/off input, we want to specify the motor torque

• With PWM, we turn the motor on/off very fast
• We can control average motor torque with duty cycle
• With a high frequency signal, the inertia of the motor smooths out the sharp on/off transitions
PWM and Direction Control
PWM and Direction Control

What happens with this input?
PWM and Direction Control

What happens?
• No current flow
PWM and Direction Control

What happens now?
PWM and Direction Control

What happens now?

• ‘x’ determines motor direction
PWM and Direction Control

Direction

Two low-current inputs control direction and torque magnitude
Diodes across the transistors can conduct current “upwards” in the circuit.
H-Bridge: More Detail

Current flow through the transistors

- Motor begins to spin

+5V
H-Bridge: More Detail

All transistors off, but:
- Motor still spinning
- Motor pushes current from left to right
H-Bridge: More Detail

All transistors off, but:
- motor still spinning

- Current moves through diode to +5V
H-Bridge: Dynamic Braking

Top transistors on;
motor spinning

[Diagram of an H-Bridge circuit with transistors and a motor symbol]
H-Bridge: Dynamic Braking

- Current moves through diode (left)
- Then through transistor (right)
H-Bridge: Dynamic Braking

- Current moves through diode (left)
- Then through transistor (right)

Motor slows itself down!
Dual H-Bridge for Project 4
Dual H-Bridge

- Left side: Teensy interface
- Right side: Motor interface

Do not mix these two!
Dual H-Bridge: Motor Side

- **GND**: battery negative
- **VIN**: battery positive
  - These are the thick power cables coming up to the circuit deck
- **OUT-A / OUT-B**
  - Connections to motor
Dual H-Bridge: Teensy Side

- **GND**: Teensy ground
- **+5V**: from supply (same as for cameras)
- **PWM**: current magnitude
- **IN-A / IN-B**:
  - 0/0: dynamic braking
  - 1/0: current flows in one direction
  - 0/1: current flows in other
  - 1/1: dynamic braking