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?
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?
NPN Transistors

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) -> 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
Simple H-Bridge

What happens with these logical inputs?
Simple H-Bridge

What happens with these logical inputs?

- Motor turns in one direction
Simple H-Bridge

How about these inputs?

+5V

0

1

1

0
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
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

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
H-Bridge: More Detail

Diodes across the transistors can conduct current "upwards" in the circuit.

![Diagram of an H-Bridge circuit with diodes and transistors labeled C0, C1, C2, and C3 connected to a 5V power source.]
H-Bridge: More Detail

Current flow through the transistors

• Motor begins to spin
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
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
Single H-Bridge
Single H-Bridge

- Left side: Teensy Interface
- Bottom side: Battery connection
- Right side: motor connection
Single H-Bridge

- **GND**: Teensy ground
- **+5V**: from supply
- **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
Single H-Bridge

Motor supply

- Do not mix up the connections!
  - Red: +, Black: -

- Never short out red and black wires on the battery
  - Connect battery connect to motor supply before connecting battery

- Smoking battery:
  - Gets hot on its own
  - Smoke is toxic
  - Move outside and dunk in water
Single H-Bridge

- OUT A/B: connection to motor
- Attach motor cable first, then connect motor