

B10 – “The Rocket Men”

CONTROL GROUP

MATTHEW GILL – 13249157

GRAHAM WHYTE - 45688158

RCGs

Requirement

- 50 ms Instruction time / Rise Time less than 50 ms
- Less than 5% overshoot
- **Satisfied**
- 2-DOF Spherical Wrist
- Simulink Model
- **Satisfied**
- Real-Time Controller
- **Satisfied**

Constraints

- 16 MHz CPU clock speed
- Budget (\$1000 UBCD + \$400 CAD)

Goals

- Everything on PCBs
- Separate Laser Power – No Dangling Wires from Diode
- Animation
- Optimal Rise – 25 ms

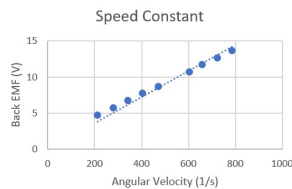
Parameter Identification

Speed Constant and Dynamic Friction Coefficient (B)

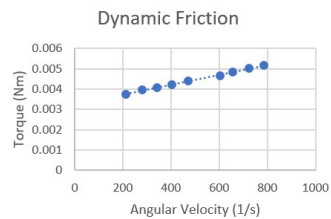
$$\epsilon = k\omega$$

$$\tau = B\omega$$

SPEED CONSTANT (K_w)
0.015547 Vs



Dynamic Friction (B)
2.42E-06 Nms

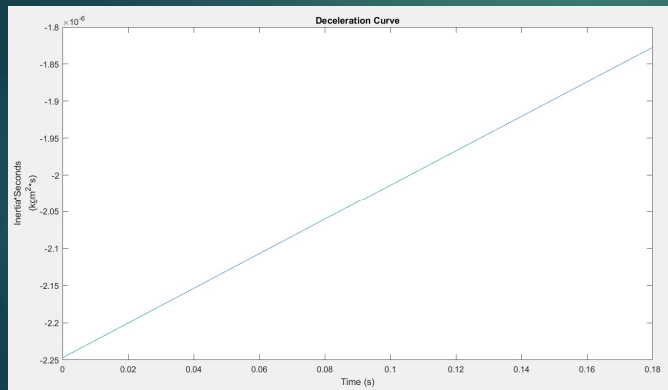


- ▶ Steady State Unloaded Voltage Tests
 - ▶ Current Draw (I) and Angular Velocity (ω) Recorded
- ▶ Back EMF (ϵ) calculated from current & terminal resistance
 - ▶ Terminal Resistance & Inductance measured with RLC meter
- ▶ Speed Constant (K) as slope of Velocity/Back EMF curve
- ▶ Friction Coefficient (B) as Slope of Torque / Speed Curve
 - ▶ Torque calculated with: $\tau = kI$

Parameter Identification

Rotor Inertia (J) - Deceleration test of unloaded motor

$$J = 8.30 \text{ gcm}^2$$



- ▶ Angular System with no external Torque:

$$0 = J\dot{\omega} + B\omega$$

then:

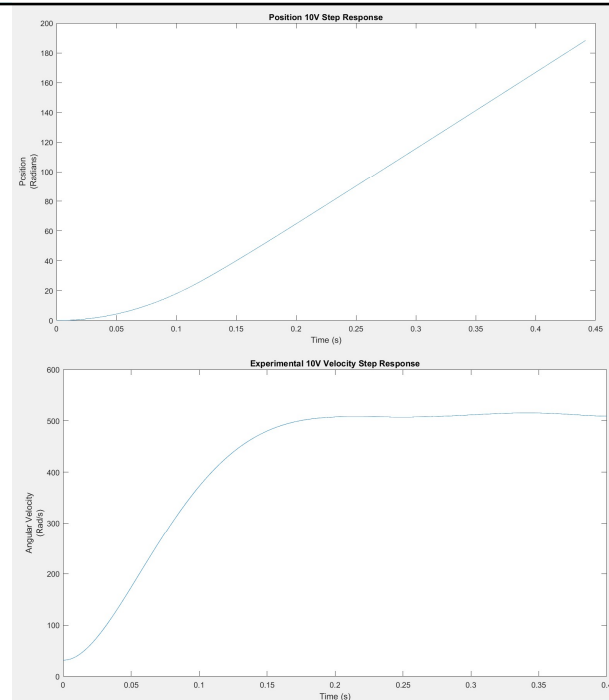
$$J \text{ is Slope of } -\frac{B*\omega(t)}{\dot{\omega}(t)} \text{ curve}$$

- ▶ Power is cut to motor running constant velocity and velocity and acceleration is recorded as motor slows

Experimental Step Response Curve Fitting

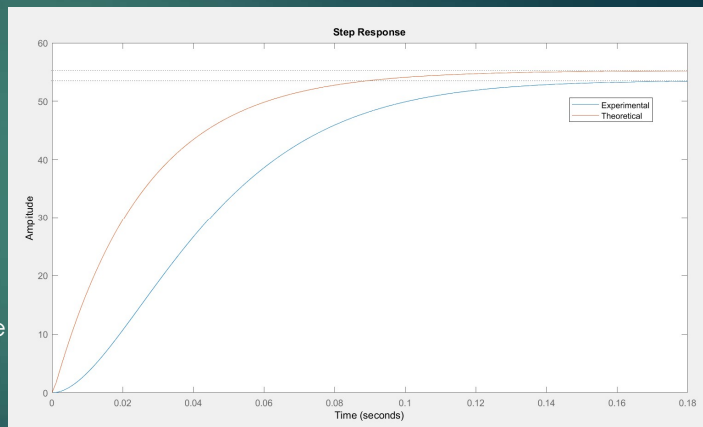
- ▶ Step test is conducted by applying a 10V step voltage to motor and recording position of motor
- ▶ The Velocity Step Response is obtained by differentiating the Position Step Response
- ▶ Utilizing MATLAB's System Identification toolkit a transfer function can then be fitted to the Velocity Response
- ▶ Transfer Function from Velocity Step Response

$$\frac{\omega(s)}{V(s)} = \frac{2.702 \times 10^4}{s^2 + 38.02s + 531}$$



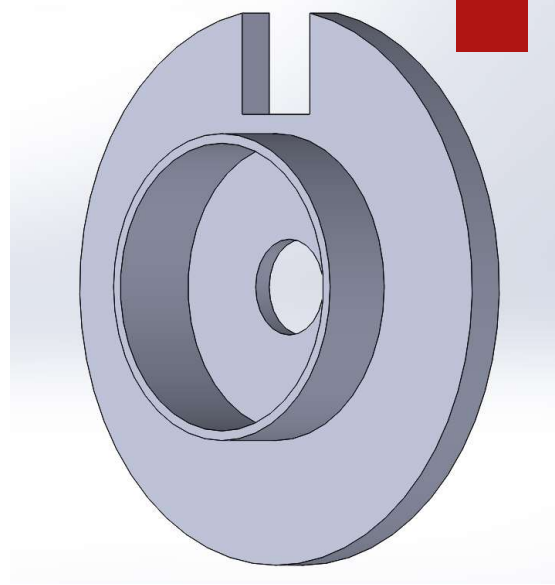
Model Verification – Step Response Comparison

- ▶ Comparison between Experimental and Modelled Step Responses helps verify model accuracy
- ▶ Possible Causes of Difference between Responses:
 - Static Friction is unmodeled
 - Accounts for initial delay of experimental response
 - Current Driver is unmodeled
 - Resistance/Capacitance/Inductance that could effect response



Encoder & Slot Detector Attachment

- ▶ Fits directly onto face of Jameco Motor.
- ▶ Slot Detector friction fitted into slot at tope of attachment
- ▶ Advantages:
 - ▶ Usable with motor oriented vertically and horizontally
 - ▶ Reusable
 - ▶ Adjustable



Mechanical System Model

▶ Encoder Disk

- ▶ Modelled as Cylinder rotating about it's Z-Axis
- ▶ Mass (m) calculated from Encoder Dimensions & density of FR4 ($1.850 \frac{g}{cm^3}$)

$$\text{▶ } J_{Encoder} = \frac{1}{2} * mr^2 = \frac{1}{2} * (5.2719)(2.4)^2 = 15.18 \text{ } gcm^2$$

▶ Laser Diode Bracket

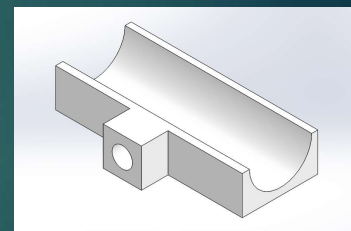
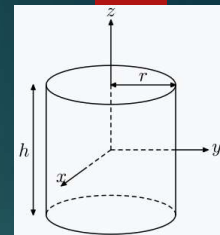
- ▶ Modelled using SolidWorks Mass Analysis & density of PLA ($1.25 \frac{g}{cm^3}$)

$$\text{▶ } J_{Bracket} = 0.177 \text{ } gcm^2$$

▶ Laser Diode

- ▶ Modelled as cylinder rotating its y – axis
- ▶ Mass Measured at 2.00 grams

$$\text{▶ } J_{Diode} = \frac{1}{12} m(3r^2 + h^2) = \frac{1}{12} * (2.00)(3(0.7)^2 + (2.1)^2) = 0.98 \text{ } gcm^2$$



Simulink – Block Diagram + Kinematics

- ▶ Allows for real time simulation of system
- ▶ Builds transfer function blocks from measured parameters
- ▶ Parameters in separate MATLAB files to allow for incremental and documented change
- ▶ Single Degree of Freedom for Laser Diode with Constant Y_d

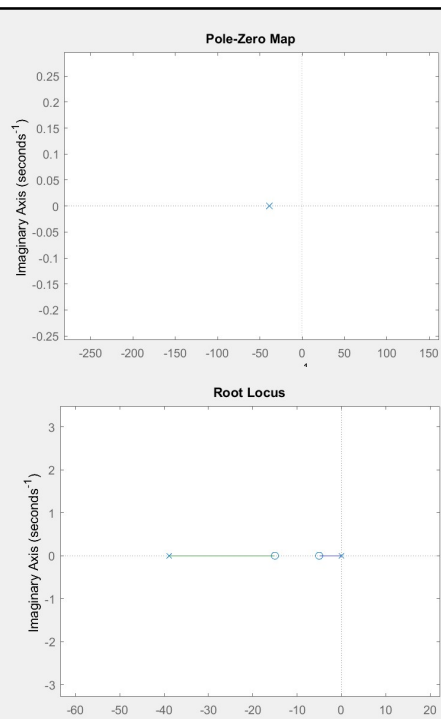
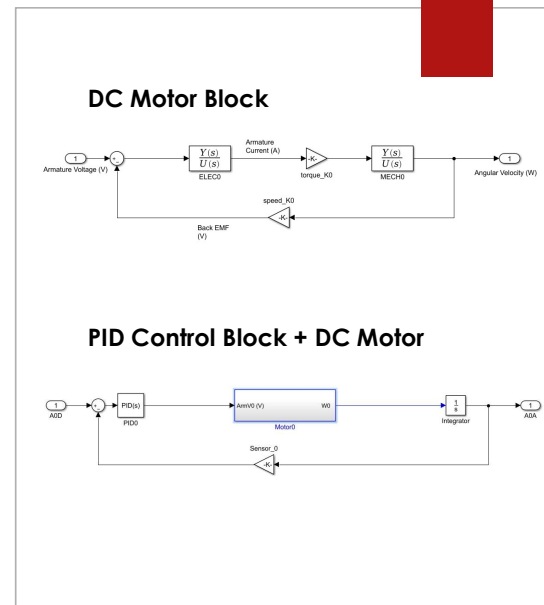
$$(X_d, Y_d) \Rightarrow \theta_D$$

Inverse

$$\theta_D = \text{atan} \frac{X_D}{Y_D}$$

Direct

$$X_A = \tan(\theta_A) * Y_A$$



PID – PZ Plot & Zero Placement & Root Locus

PZ Plot

- ▶ Additional Pole at $S = -3000$
 - ▶ Assuming contribution is negligible

Starting Zero Placement

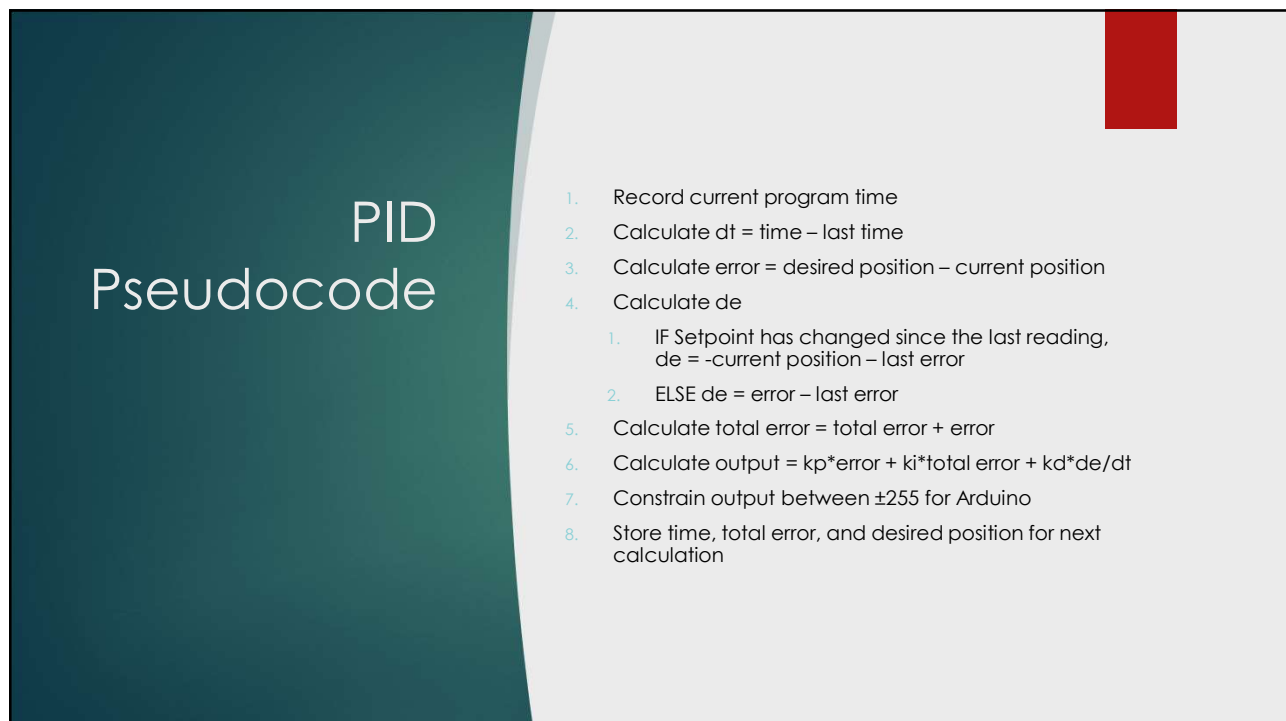
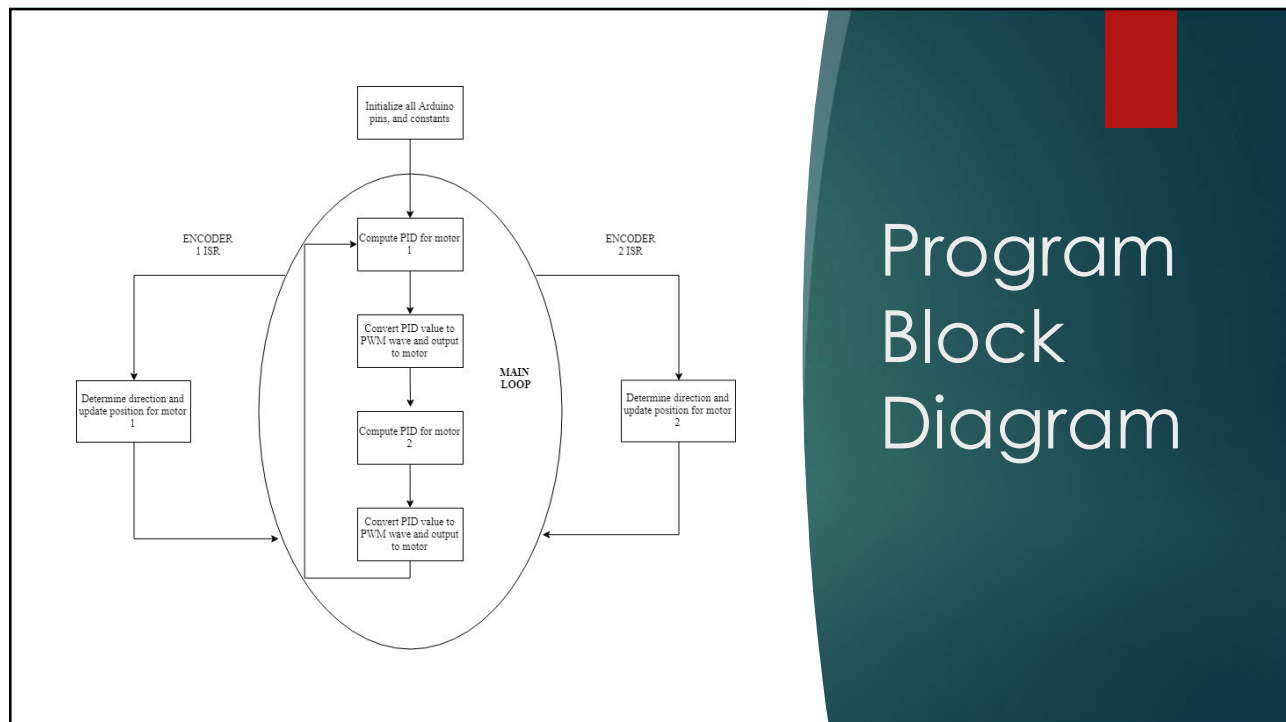
- ▶ $(s + 5)(s + 15)$
- ▶ Draw Pole at Zero to left for me stability
- ▶ Draw Pole on the left to right for improved response time
- ▶ No K_U

Starting Gains

$$K_D = 0.0400$$

$$K_P = 0.30$$

$$K_I = 0.80$$



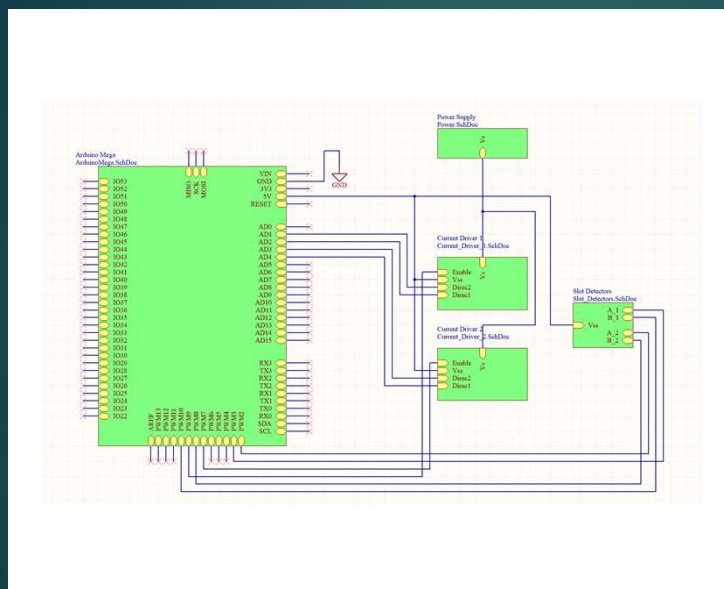
Microcontroller Selection

Arduino Uno

- ▶ Interrupt pins: 2
- ▶ PWM pins: 6
- ▶ RAM: 2kB
- ▶ Readily available and easy to build PCB around

Arduino Mega

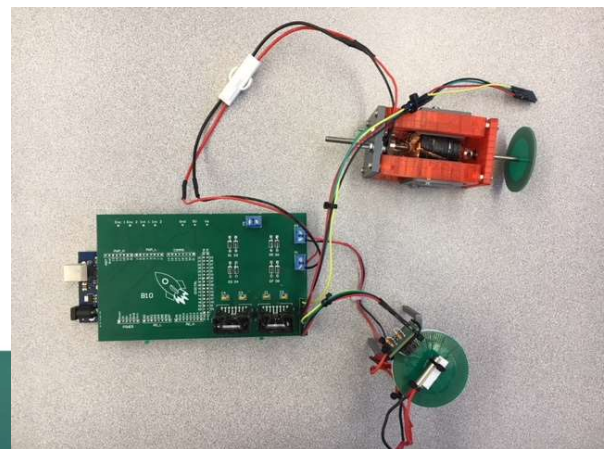
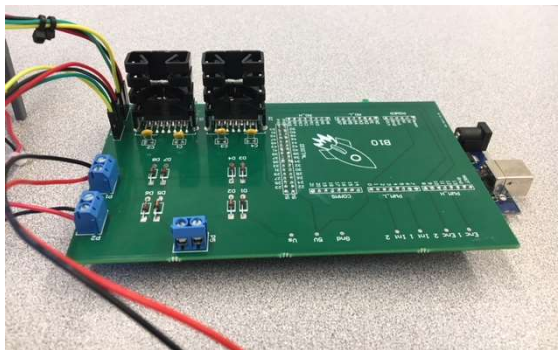
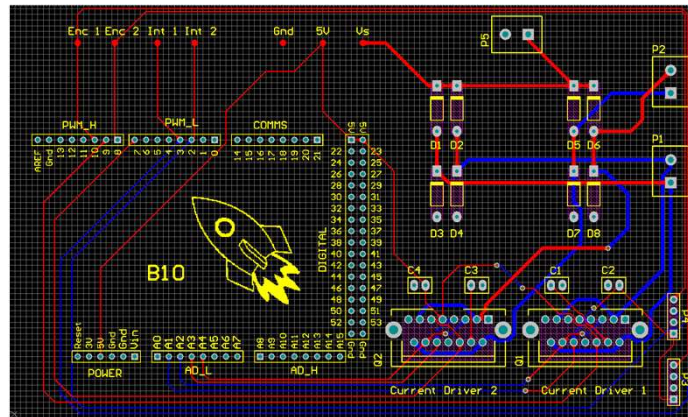
- ▶ Interrupt pins:
- ▶ PWM pins: 15
- ▶ RAM: 8kB
- ▶ Need to order in, challenging to build PCB around



PCB Top
Level
Design

PCB Layout

- All ground connections connected to polygon pour



PCBA

Encoder ISR Pseudocode

1. ISR triggers on falling edge of Slot Detector A
2. Check state of Slot Detector B
 1. If Slot Detector B is high, direction is forwards
 1. Increment displacement (number of interrupts from initial position)
 2. If Slot Detector B is low, direction is backwards
 1. Decrement displacement
3. Convert displacement to radians:

$$Displacement_{rad} = Displacement * \frac{3.6}{180}$$

PCB Future Improvements

- ▶ Reduce noise from custom motor
 - ▶ Add mechanical cutout between motors
 - ▶ Replace ground plane with multiple small ground planes that don't come near motors
 - ▶ Add capacitor across motor terminals
 - ▶ Add small inductors in series with motors to prevent large currents in one motor from affecting the other
- ▶ Reduce size of PCB
 - ▶ Remove Arduino daughter board
- ▶ Add additional power ports
 - ▶ Banana plugs, barrel connector

Summary

- ▶ Currently Have Operational Real-Time Controlled 1-DOF System
 - ▶ Satisfactory Overshoot
- ▶ Fully operational Parameter Acquisition Procedure
- ▶ Accurate Model of System
- ▶ Alpha Version of PCB designed and manufactured

