

Laser Light Show

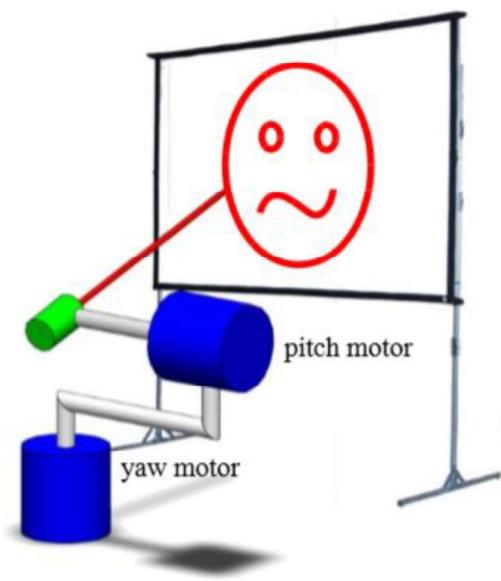
Integrated System: B2

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Introduction

Integrated Team Goal:

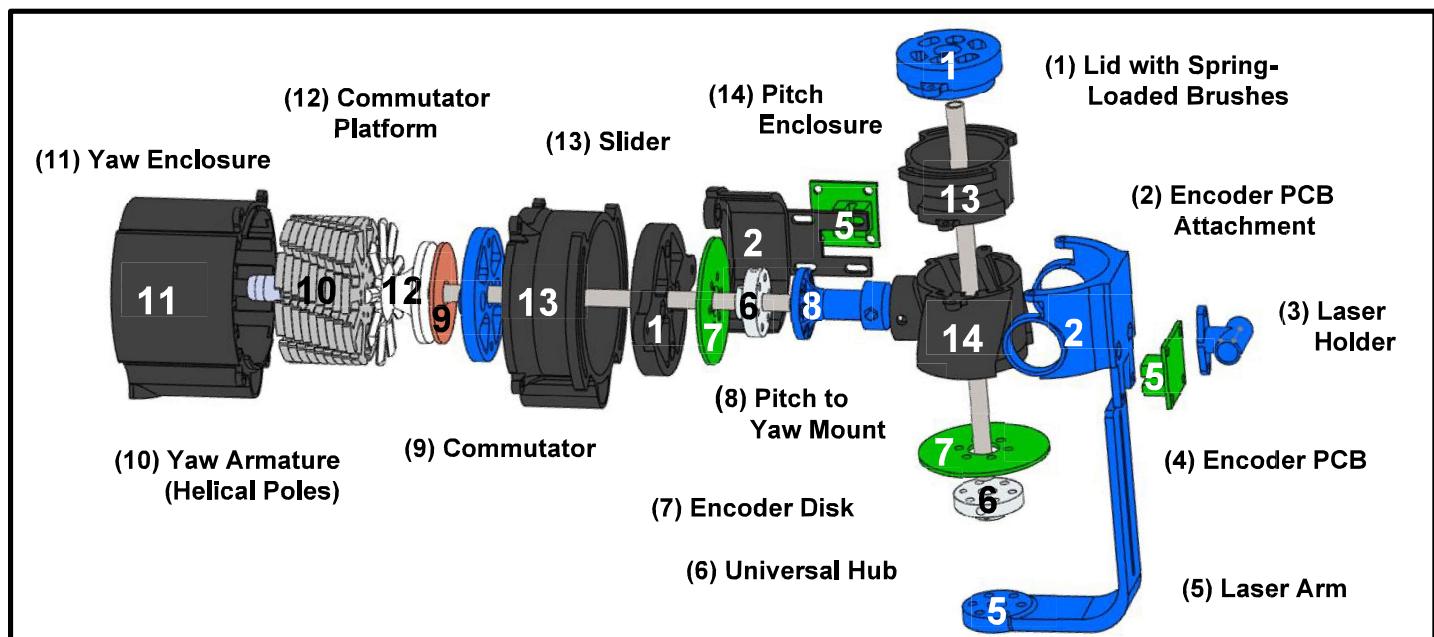
- Design and build **2 DC actuators**
 - Mechanically commutated
 - Rotary
 - Permanent Magnet
- Design and build a **2-DOF electromechanical system** to position a **laser pointer**
- Develop **controls** for the system
 - Create optical **animations**



System RCGs

Component	Requirements	Constraints	Goals
Motors	<ul style="list-style-type: none"> - Self-starting - Operate CW & CCW - Rotate at 2Hz - Yaw can support pitch 	<ul style="list-style-type: none"> - 20VDC / 4A max power (PSU power) - 3D printed enclosure, waterjet laminations 	✓ Self-starting at <500mA ✓ Oscillate at $\geq 5\text{Hz}$
Control	<ul style="list-style-type: none"> - PID rate at 500us - Error < 10 degrees - No missed encoder readings - No encoder slippage 	<ul style="list-style-type: none"> - Current driver $\leq 4\text{A}$ - Decoder speed $\leq 33\text{ MHz}$ 	✗ Error < 1 degree ✓ Implement limit switches ✗ Operate motors with 1 driver

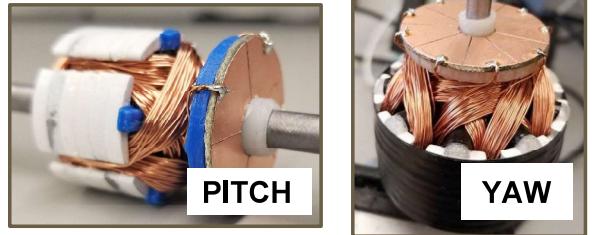
High Level Design: Electromechanical System



Detailed Design: Rotors

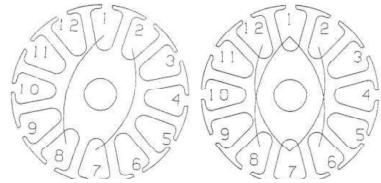
Laminations

- Used steel for optimal electromagnet hysteresis
- Designed yaw to stack helically, with a 20° angle
 - Minimized cogging
- Derived rotor parameters to ensure support of pitch
 - Maximized torque of yaw
 - Minimized weight of pitch



Winding Technique

- Used lap winding technique to allow for larger current
 - Allows more parallel paths for current to flow
- Evenly wound to prevent mechanical imbalance

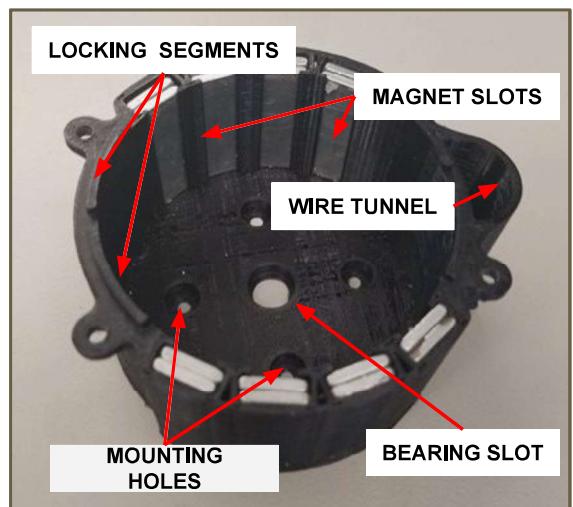


Lap Winding Technique

Detailed Design: Yaw Enclosure

Features

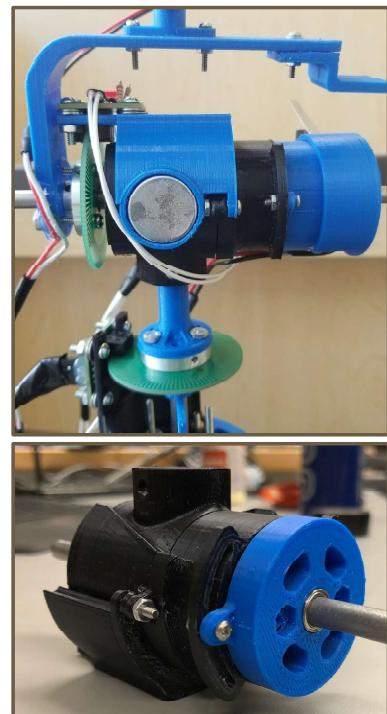
- Minimized air gap between magnets and rotor to 2mm
 - Curved slotting structure
- Considered 3D printing tolerances for precise bearing slot alignment
- Implemented double locking mechanism
 - Locking segments
 - Nut/bolt holes locking tabs
- Used 4 base mounting screw holes
 - Secure enclosure and prevent vibration
- Designed wire routing “tunnel”
 - Wire management for power leads



Detailed Design: Pitch Enclosure

Features

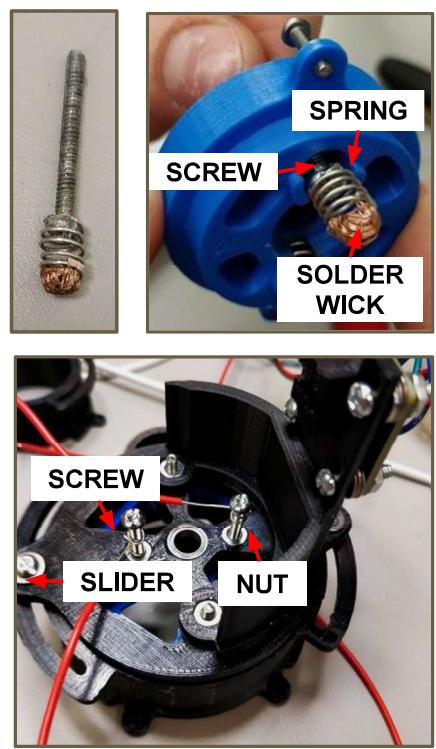
- Helical magnet slotting structure
 - Reduce cogging
- Platform to secure encoder PCB
 - Includes slot for extra magnets
 - Increase B field if necessary
- Mounting holes to secure lid/enclosure/cuff structure
- Pitch to yaw motor attachment cylinder
 - Secure pitch for rotation



Detailed Design: Brushes

Brushes

- Looped 22 AWG wire around a rod to make springs
- Soldered copper braided-wire to springs
 - Minimized friction; prevented sparks; increased conductivity
- Soldered spring to a screw head
 - Adjustable screw pressure



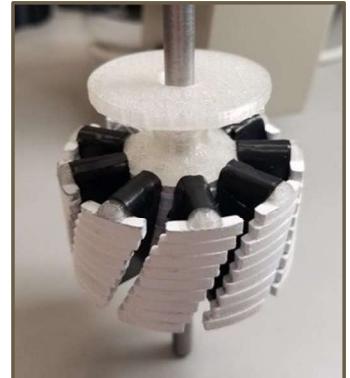
Slider System

- Developed a sliding lid to allow rotation
 - Ensured optimal position of brushes

Detailed Design: Commutator

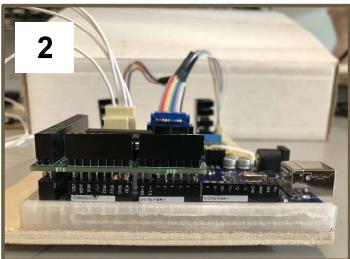
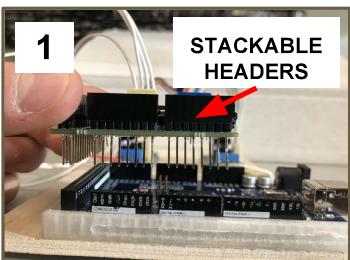
Disk Commutator

- Used protractor to measure and cut equal segments
- 3D printed a platform to mount disk
 - Secured by glue, electrical tape, and windings
 - Ensured commutator was level
- Created a nylon tube to insulate commutator from shaft
 - High melting point: 265 °C
 - Will not melt with commutator sparks



Detailed Design: Printed Circuit Boards

DIGITAL ELECTRONICS BOARD (DEB)

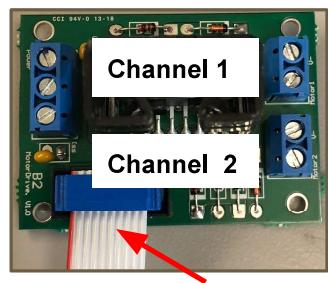


5-pin latch connector to Encoder pcb + homing limit switch

Reliable wiring Connections

10 pin IDE connector to Motor Drive

2 CHANNEL MOTOR DRIVER



10 pin IDE connector to DEB

Detailed Design: Motor Parameterization

FORMULAS

$$V_{BackEMF} = V_{Measured} - I_{Measured} * R_{Measured}$$

$$K_e = \frac{V_{BackEMF}}{\omega_{Measured}}$$

$$K_t = K_e$$

$$B = \frac{K_t * I_{Measured}}{\omega_{Measured}}$$

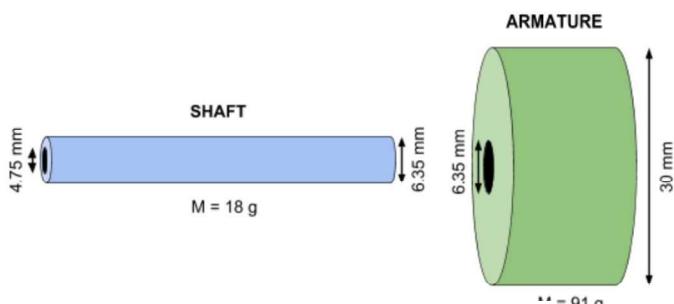


Fluke PM6303A used
to measure **R** and **L**

Parameter	Yaw Motor	Pitch Motor
R (Ω)	2.5	1.8
L (mH)	3.5	0.58
K_e (mV/Rad/s)	63.1	5.64
K_t (mNm/A)	63.1	5.64
B (mNmms/rad)	241	28.5

Detailed Design: Motor Parameterization

PITCH MOTOR



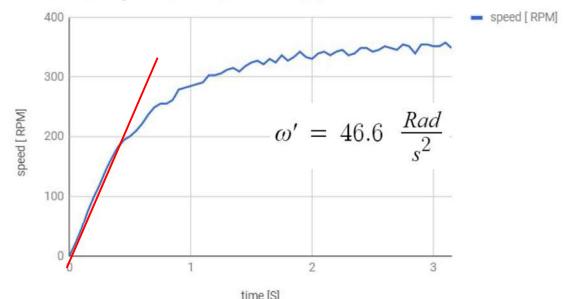
$$J = \frac{m}{2} (r_1^2 + r_2^2)$$

$$J_{Pitch} = J_{Shaft} + J_{Armature}$$

$$J_{Pitch} = 10.8 \text{ kgmm}^2$$

YAW MOTOR

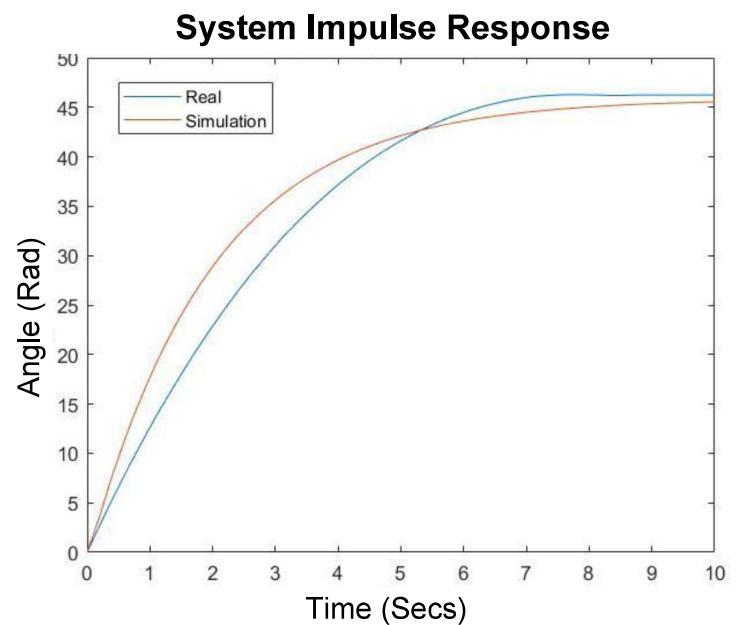
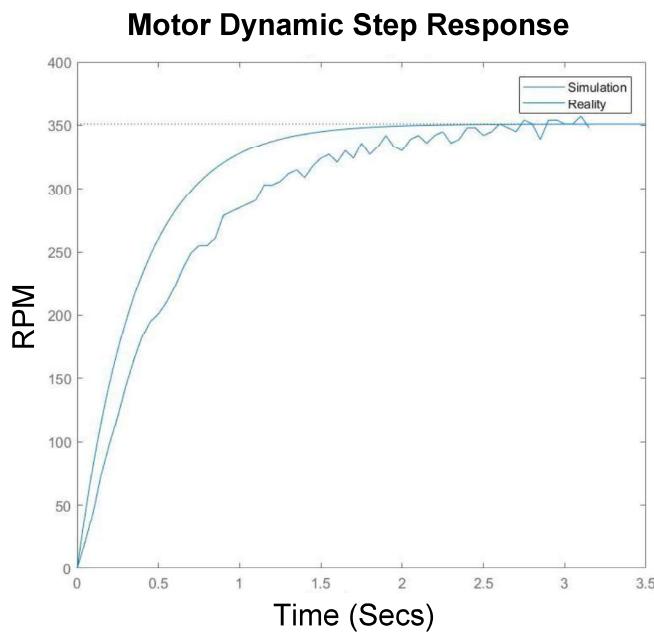
Yaw Motor speed [RPM] vs. time [S]



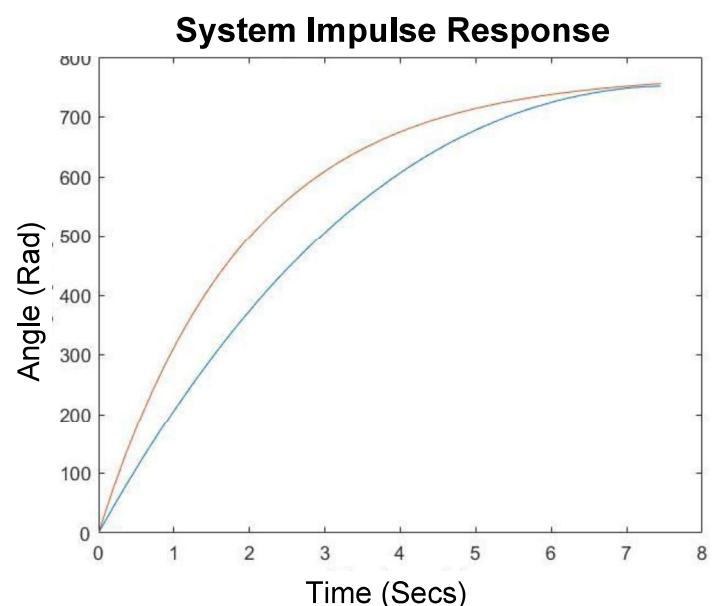
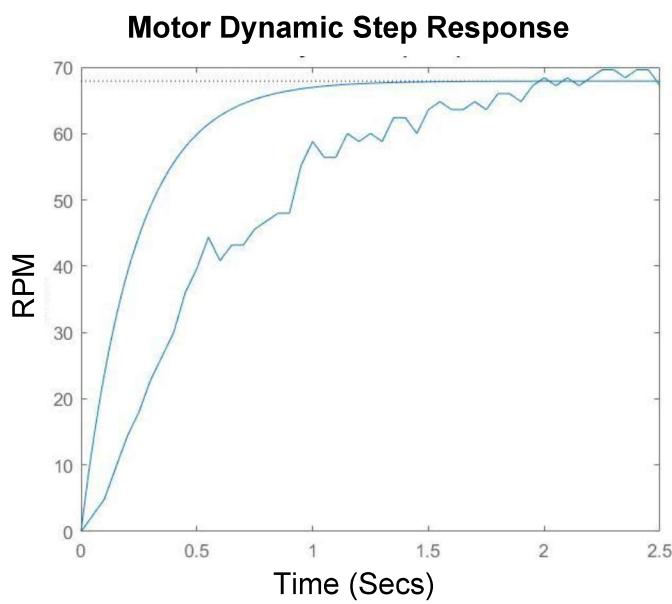
$$J_{Yaw} = \frac{K_t * I_{Measured}}{\omega'_{Measured}}$$

$$J_{Yaw} = 678 \text{ kgmm}^2$$

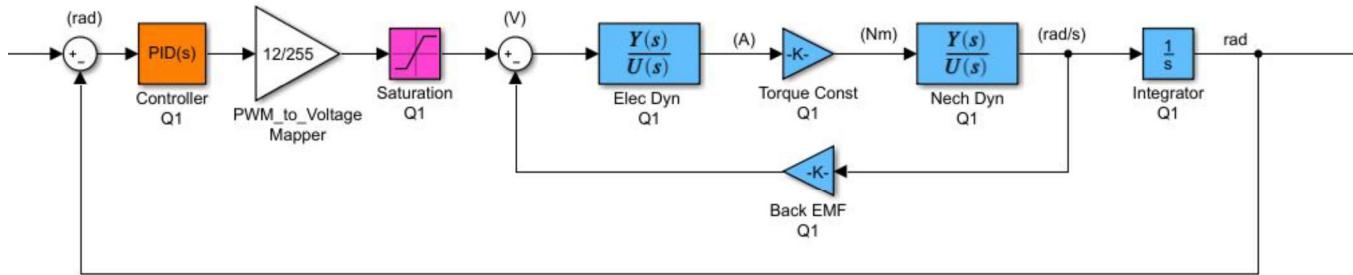
Detailed Design: Yaw Step and Impulse Responses



Detailed Design: Yaw Step and Impulse Responses



Detailed Design: Simulink Modelling



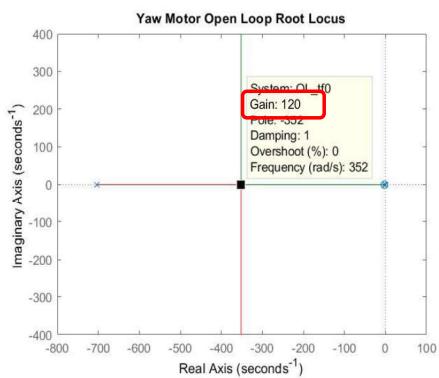
$$TF_{YawMotorOpenLoop} = \frac{1032.5}{s(s + 703.9)(s + 2.719)}$$

$$TF_{PitchMotorOpenLoop} = \frac{21008}{s(s + 3075)(s + 4.276)}$$

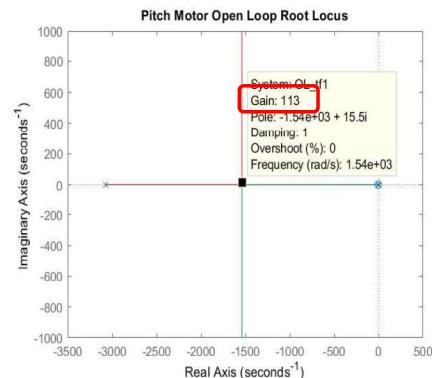
We first implemented a **PD controller** as the pole at zero only allows us to cancel **one pole**

Detailed Design: Simulink Modelling

YAW MOTOR

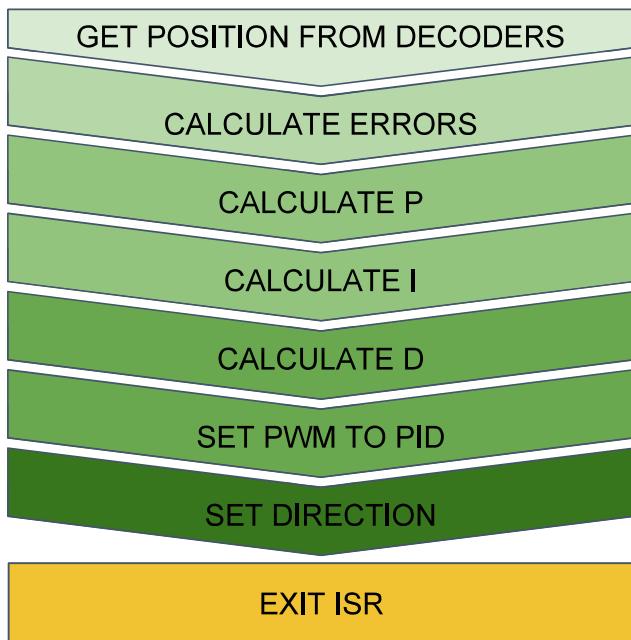


PITCH MOTOR



	Kp	Kd
Yaw Motor	326.28	120
Pitch Motor	483.188	113

Detailed Design: PID Implementation



PID TERM CALCULATIONS:

PROPORTIONAL	$P = K_p * \text{error}$
INTEGRAL	$I = K_i * (\text{I} + \text{error})(dt)$
DERIVATIVE	$D = K_d * (\text{error} - \text{prevError})/(dt * N)$

prevError is calculated every N cycles
dt is our interrupt speed

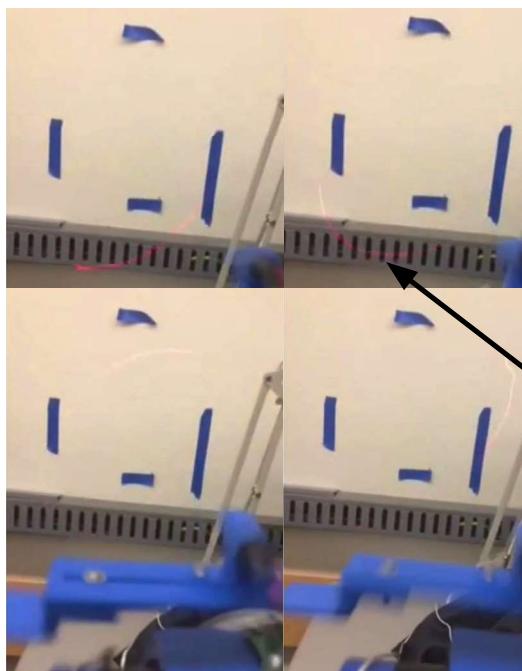
PID CALCULATION:

$$\text{PID} = P + I + D$$

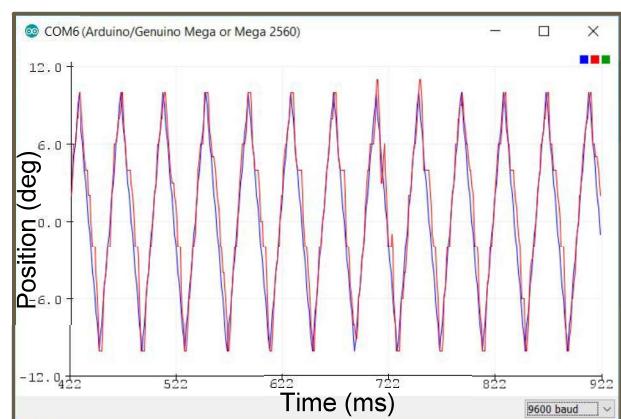
$-255 < \text{PID} < 255$, $\text{PWM} = \text{PID}$

PID Tuning: We adjust **K_p** for **Overshoot**, **K_d** for damping, and **K_i** for **non-linearities** not accounted for in our Simulink Model

Results & Validation: Drawing Shapes



Laser beam
trace at
 ~ 10 Hz

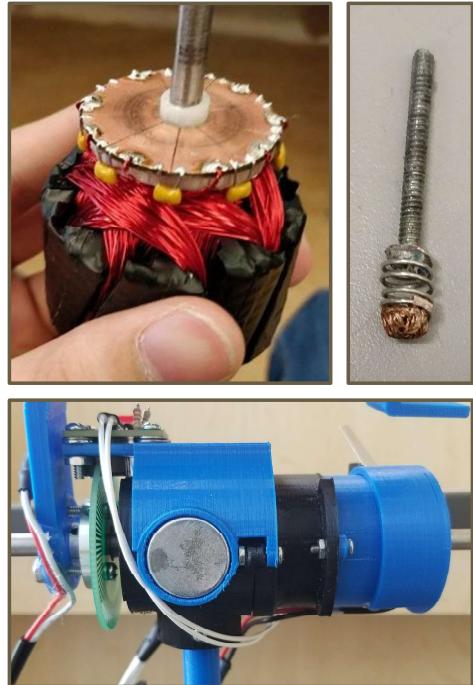


Live graphing of **Intended Setpoint** and **Actual Position** showing the accuracy of our integrated setup

Note: tape does not represent boundaries of laser

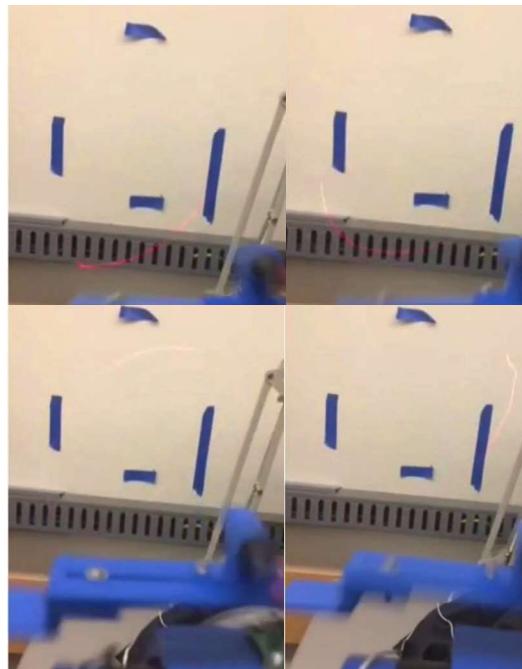
Lessons Learned

1. Rotor shorted with magwire (electromagnets)
Solution: *insulated poles with electrical tape*
2. Motors produced EMI that affected encoder readings
Solution: *added capacitors between commutator segments*
3. Brushes increased friction
Solution: *created brushes out of soft copper braid*
4. Inconsistent brush/commutator connection
Solution: *added brush springs to maintain contact*
5. Motor favoured one direction
Solution: *designed sliding lid mechanism to optimize bidirectional rotation*
6. Weak permanent magnets on pitch motor
Solution: *built magnet holes into encoder PCB platform*



Summary

- Built 2 mechanically commutated DC actuators
- Developed an electromechanical system to position a laser pointer
- Integrated a control system
 - Motor parameters
 - PID
- Optimized the system to draw a circle at 10 Hz



Laser beam trace at ~10 Hz