Laser Light Show

Integrated System: B2

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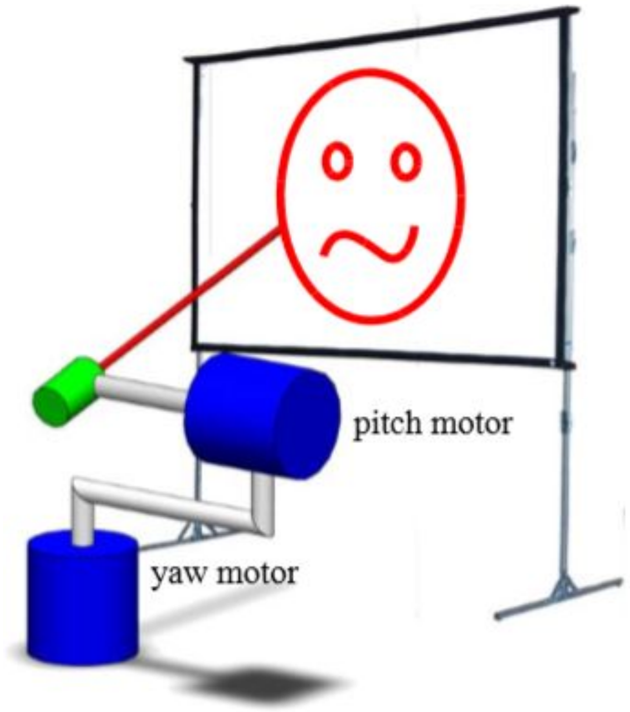
Introduction

Integrated Team Goal:

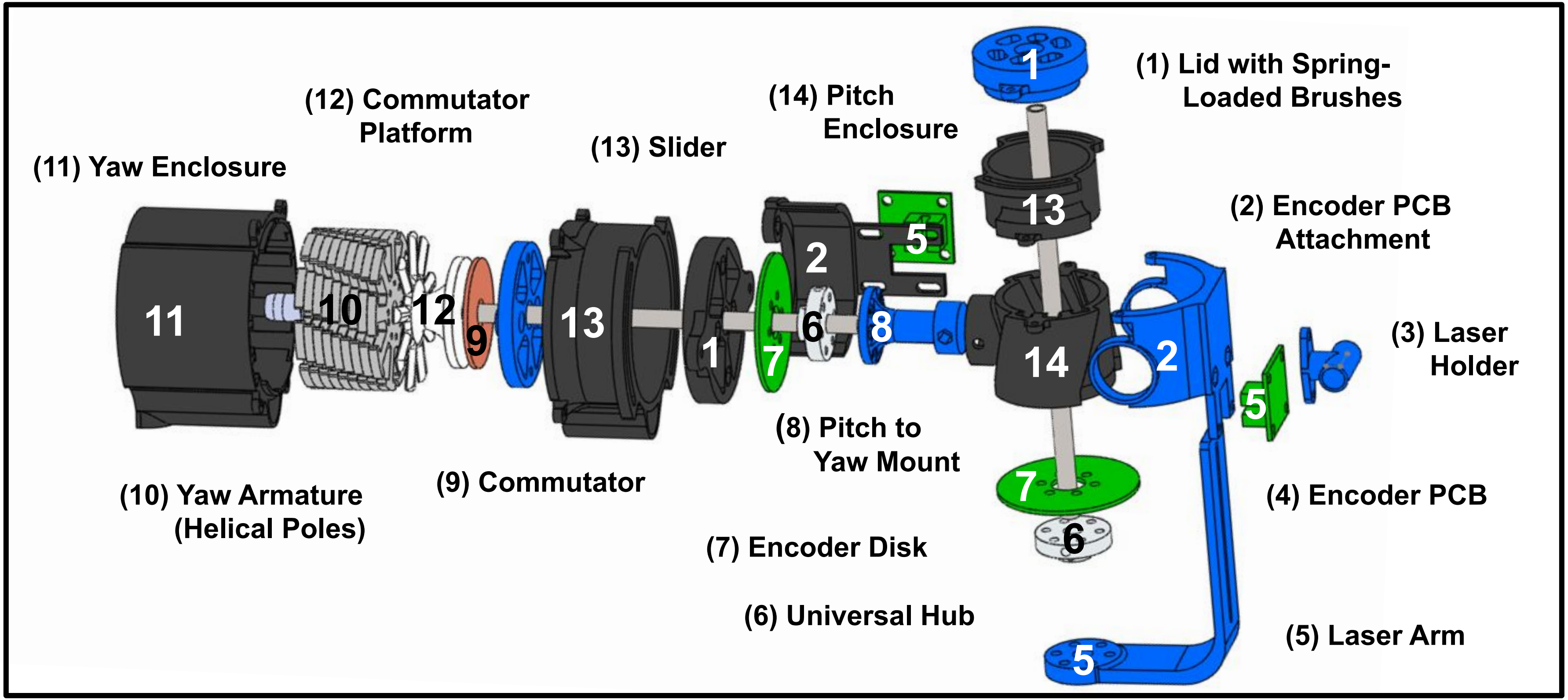
- Design and build **2 DC actuators**
  - Mechanically commutated
  - Rotary
  - Permanent Magnet
- Design and build a **2-DOF electromechanical** system to position a **laser pointer**
- Develop **controls** for the system
  - Create optical **animations**



System RCGs

Component	Requirements	Constraints	Goals
Motors	- Self-starting - Operate CW & CCW - Rotate at 2Hz - Yaw can support pitch	- 20VDC / 4A max power (PSU power) - 3D printed enclosure, waterjet laminations	✅ Self-starting at <500mA ✅ Oscillate at ≥ 5Hz
Control	- PID rate at 500us - Error < 10 degrees - No missed encoder readings - No encoder slippage	- Current driver ≤ 4A - Decoder speed ≤ 33 MHz	❌ Error < 1 degree ✅ Implement limit switches ❌ Operate motors with 1 driver

High Level Design: Electromechanical System



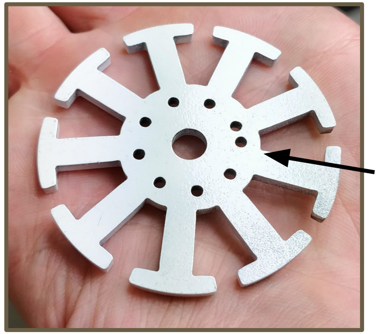
Detailed Design: Rotors

Laminations

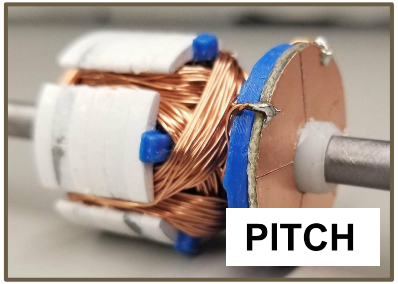
- Used steel for optimal electromagnet hysteresis
- Designed yaw to stack helically, with a 20° angle
  - Minimized cogging
- Derived rotor parameters to ensure support of pitch
  - Maximized torque of yaw
  - Minimized weight of pitch

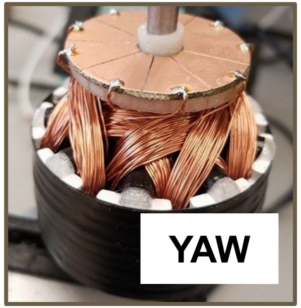
Winding Technique

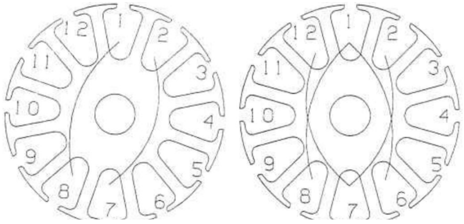
- Used lap winding technique to allow for larger current
  - Allows more parallel paths for current to flow
- Evenly wound to prevent mechanical imbalance



Helical Alignment Holes





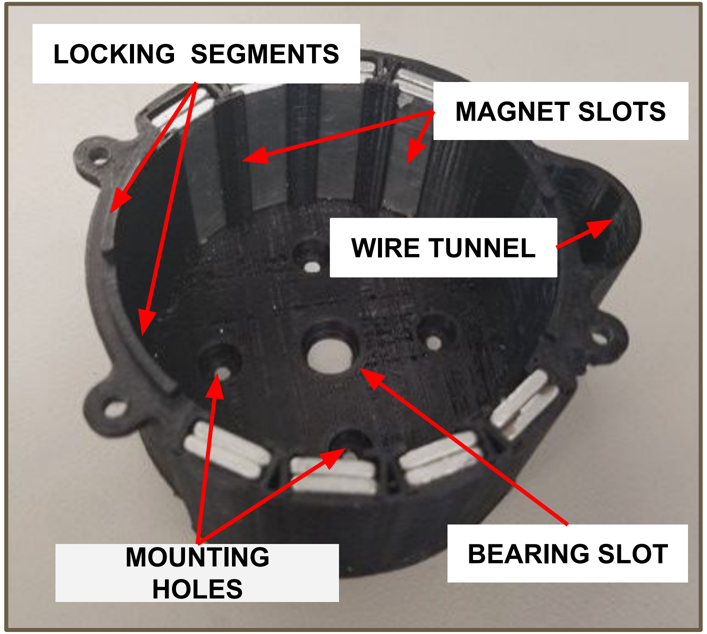


Lap Winding Technique

Detailed Design: Yaw Enclosure

Features

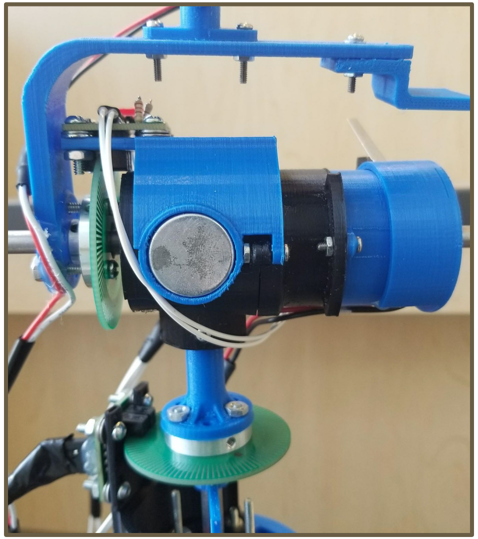
- Minimized air gap between magnets and rotor to 2mm
  - Curved slotting structure
- Considered 3D printing tolerances for precise bearing slot alignment
- Implemented double locking mechanism
  - Locking segments
  - Nut/bolt holes locking tabs
- Used 4 base mounting screw holes
  - Secure enclosure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

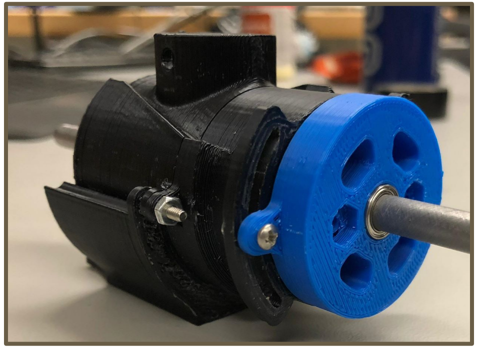


Detailed Design: Pitch Enclosure

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





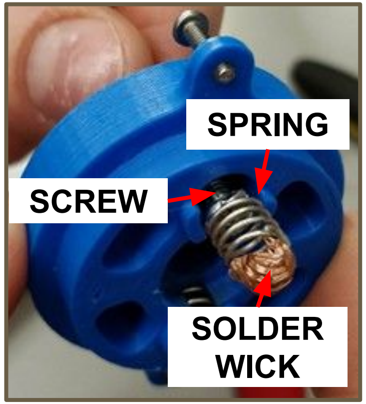
Detailed Design: Brushes

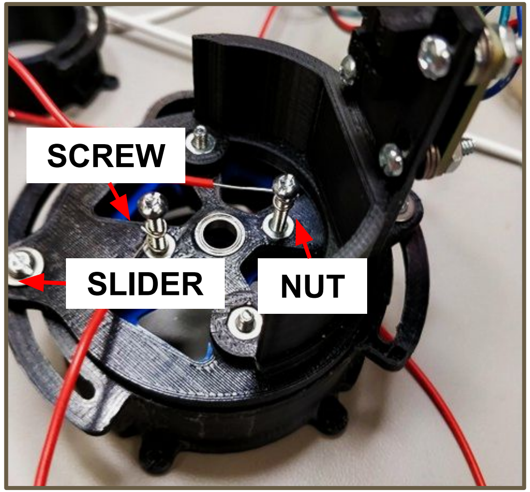
Brushes

- 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

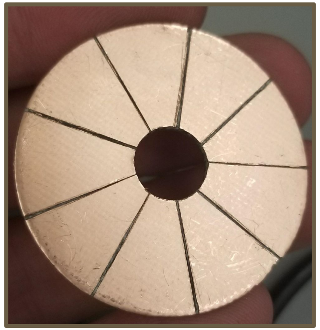


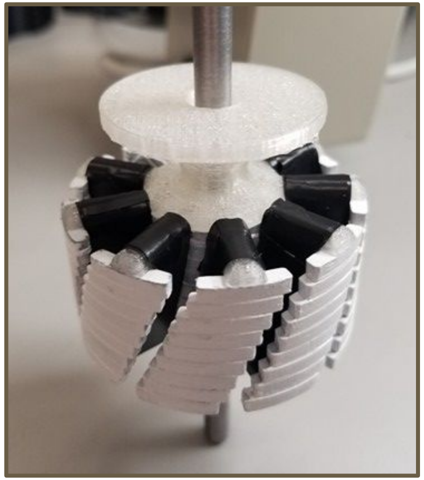


Detailed Design: Commutator

Disk Commutator

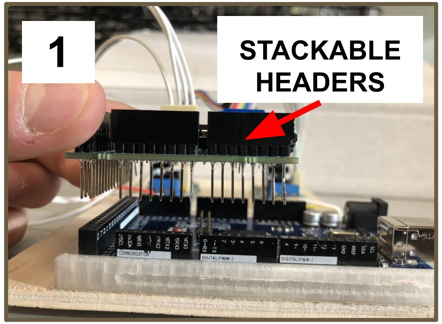
- Used protractor to measure and cut equal segments
- 3D printed a platform to mount disk
  - Secured by glue, electrical tape, and windings
  - Ensured commutator was level
- Created a nylon tube to insulate commutator from shaft
  - High melting point: 265 °C
    - Will not melt with commutator sparks

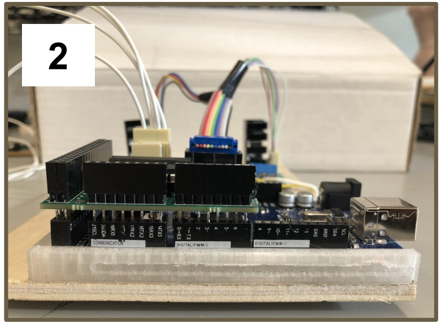


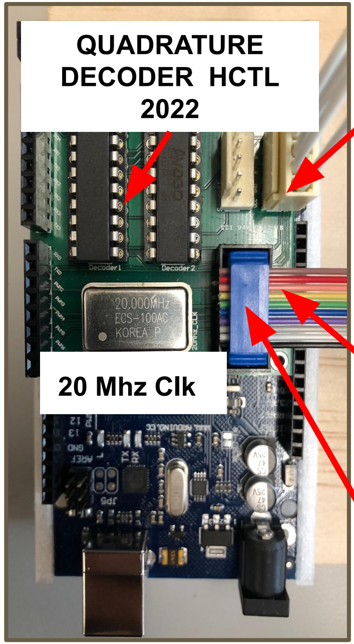


Detailed Design: Printed Circuit Boards

DIGITAL ELECTRONICS BOARD (DEB)





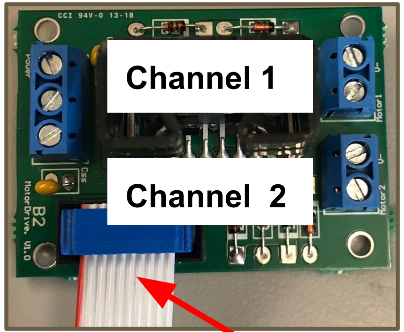


5-pin latch connector to Encoder pcb + homing limit switch

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

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

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

$$K_t = K_e$$

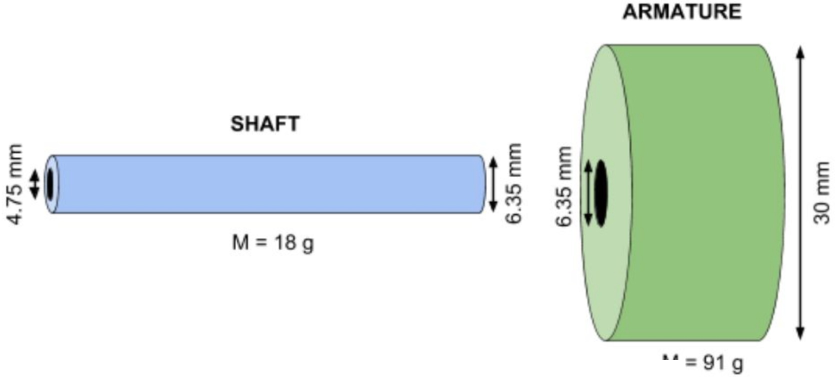
$$B = \frac{K_t * I_{Measured}}{\omega_{Measured}}$$

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

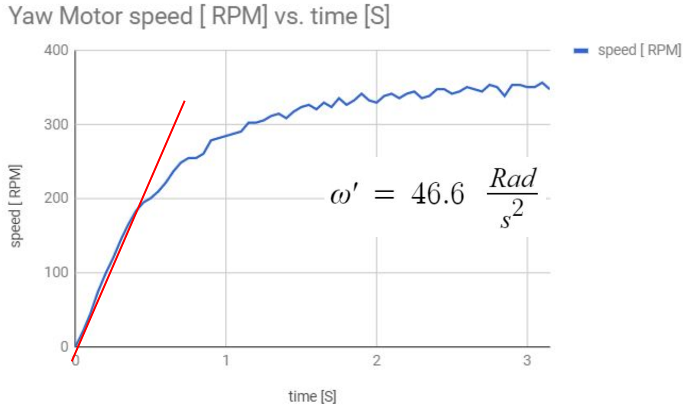


$$J = \frac{m}{2}(r_1^2 + r_2^2)$$

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

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

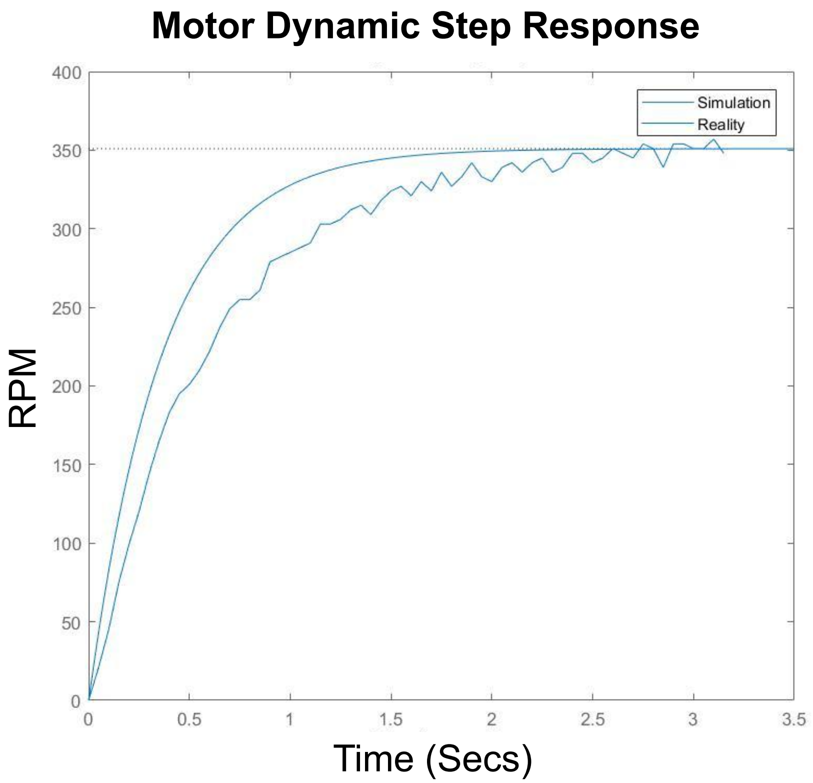
YAW MOTOR

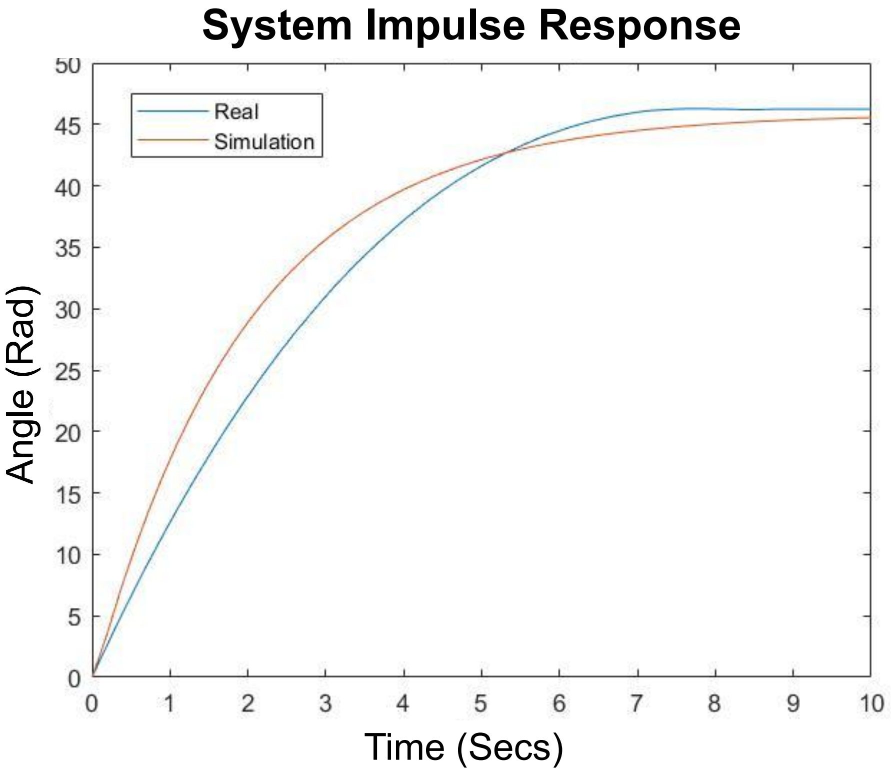


$$J_{Yaw} = \frac{K_t * I_{Meaured}}{\omega'_{Measured}}$$

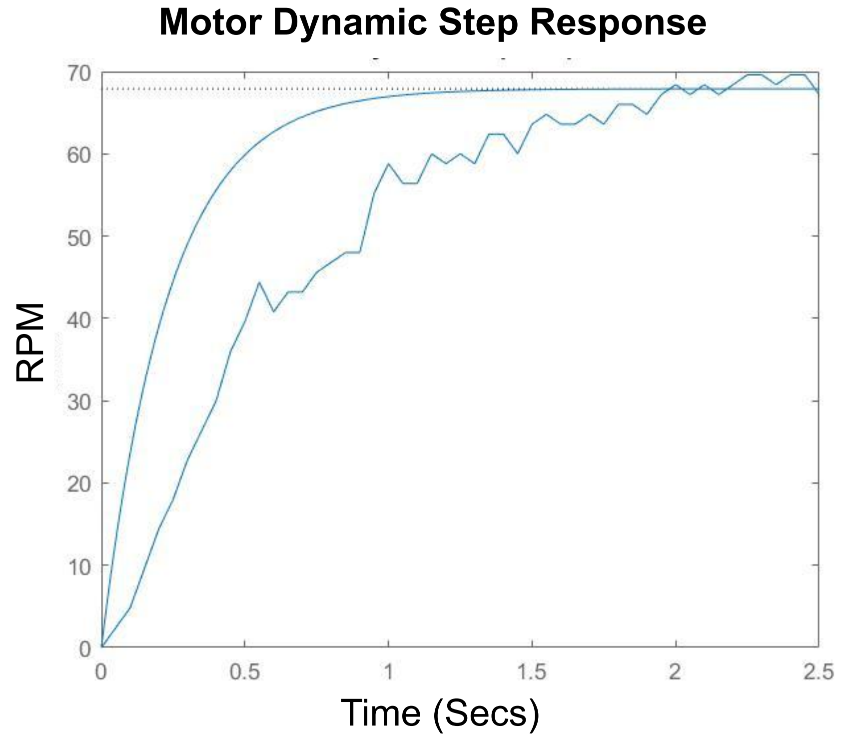
$$J_{Yaw} = 678\ kgmm^2$$

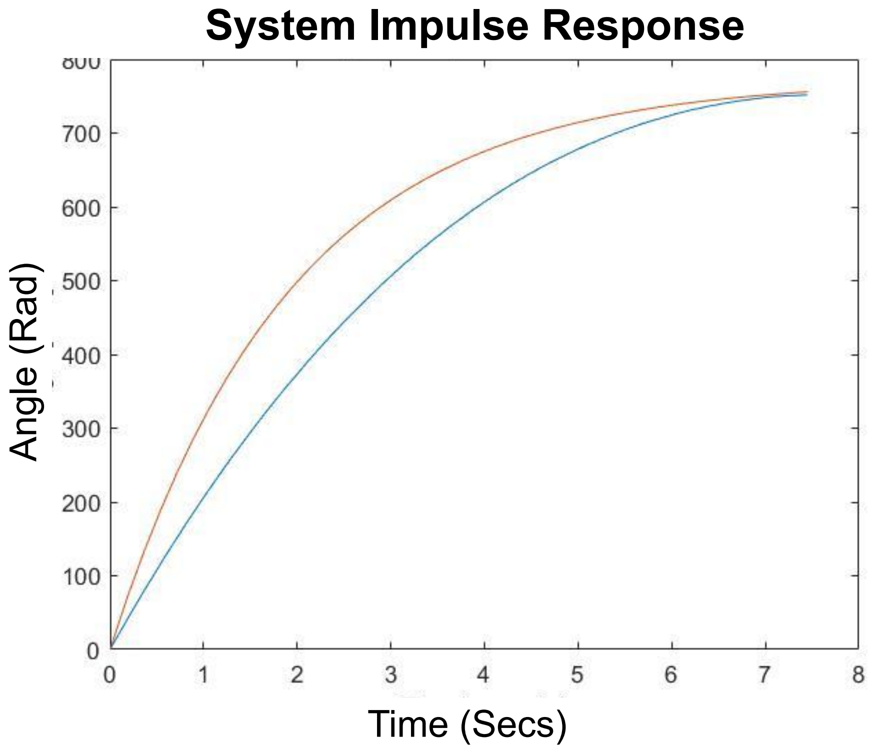
Detailed Design: Yaw Step and Impulse Responses



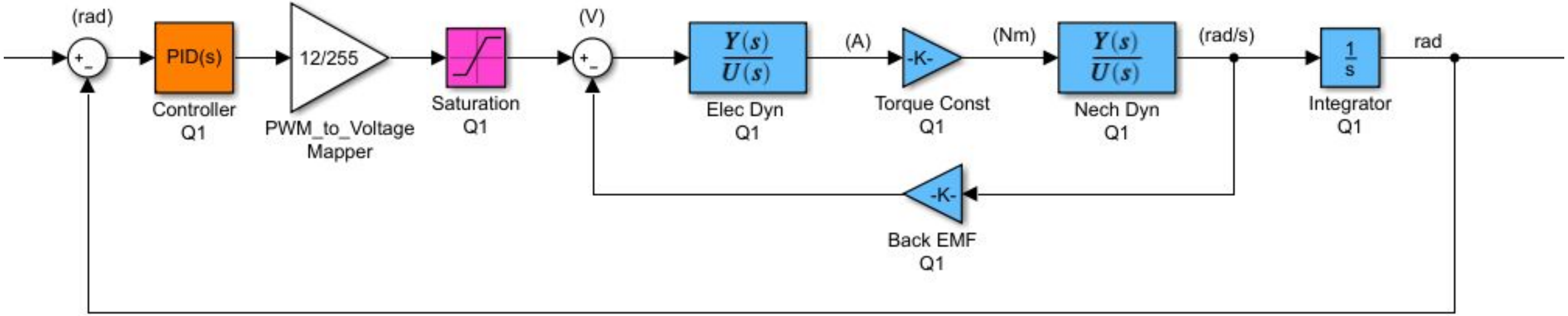


Detailed Design: Yaw Step and Impulse Responses





Detailed Design: Simulink Modelling



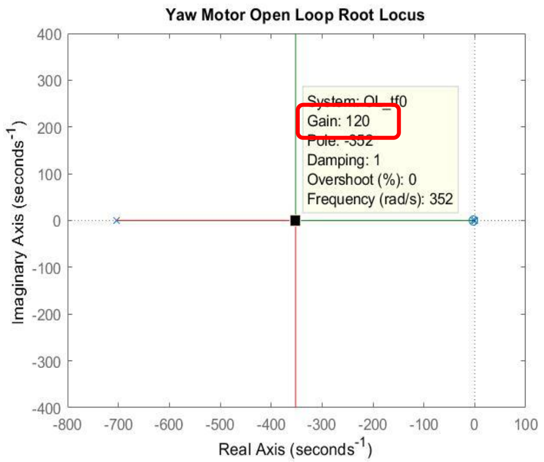
$$TF_{YawMotorOpenLoop} = \frac{1032.5}{s(s+703.9)\cancel{(s+2.719)}}$$

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

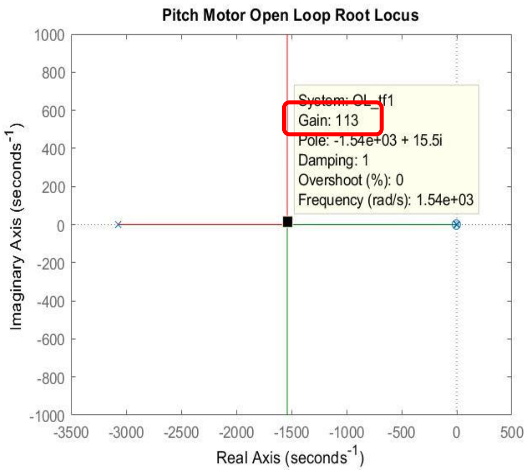
We first implemented a **PD controller** as the pole at zero only allows us to cancel **one pole**

Detailed Design: Simulink Modelling

YAW MOTOR



PITCH MOTOR



	Kp	Kd
Yaw Motor	326.28	120
Pitch Motor	483.188	113

Detailed Design: PID Implementation

- GET POSITION FROM DECODERS
- CALCULATE ERRORS
- CALCULATE P
- CALCULATE I
- CALCULATE D
- SET PWM TO PID
- SET DIRECTION
- EXIT ISR

PID TERM CALCULATIONS:

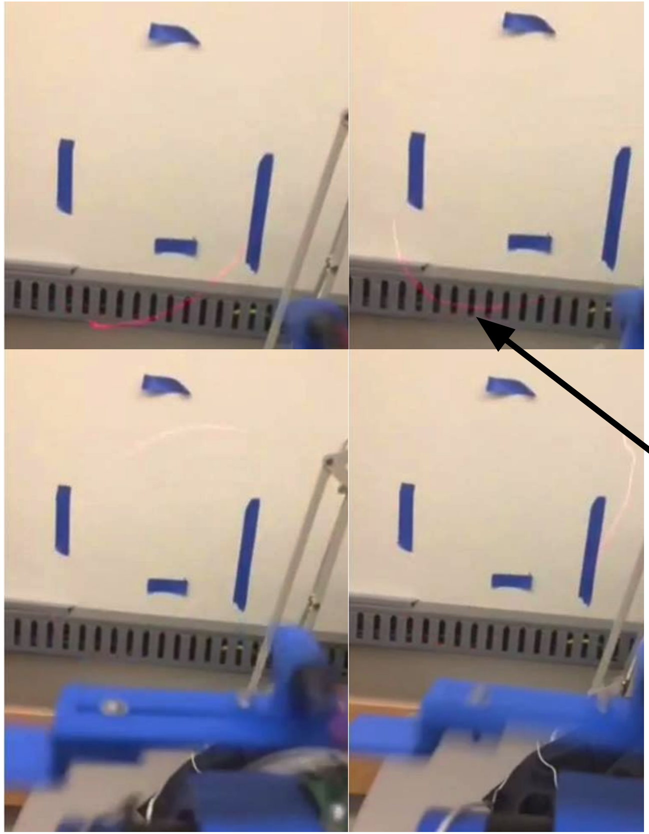
PROPORTIONAL	P = Kp * error
INTEGRAL	I = Ki * (I + error)(dt)
DERIVATIVE	D = Kd * (error - prevError)/(dt * N)

prevError is calculated every **N cycles**
dt is our **interrupt speed**

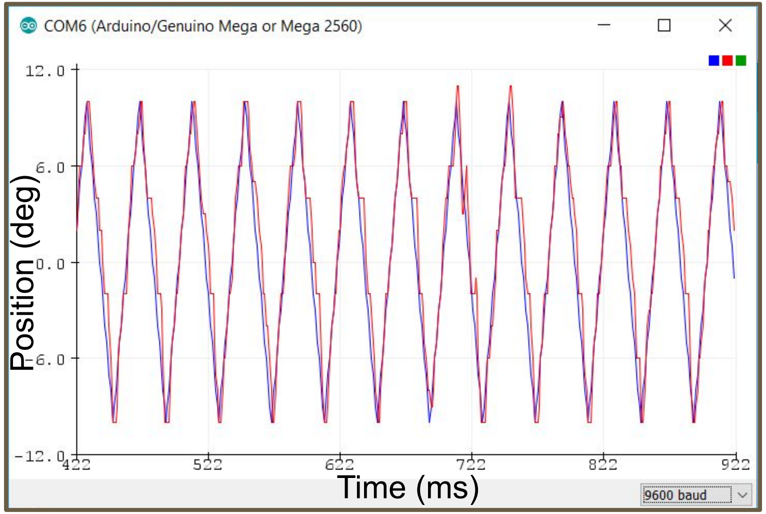
PID CALCULATION:
PID = P + I + D
-255 < PID < 255, PWM = PID

PID Tuning: We adjust **Kp** for **Overshoot**, **Kd** for damping, and **Ki** for **non-linearities** not accounted for in our Simulink Model

Results & Validation: Drawing Shapes



Laser beam trace at ~10 Hz

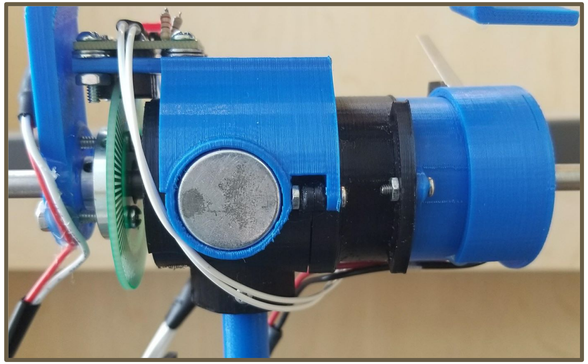


Live graphing of **Intended Setpoint and Actual Position** showing the accuracy of our integrated setup

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