Wenoa Teves
26124157

Muchen He
44638154

Ou (Leo) Liu
18800152

Lufei Liu
14090154

ELEC 391

TEAM B1

RCGs

- Achieved
- Attempted

Requirements

- Draw with laser light
- Implement with DC motors

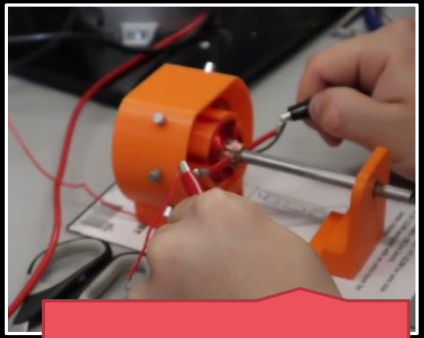
Constraints

- Control Frequency of 3000 Hz due to speed of code execution time
- Max Motor Current (< 2A per motor)
- Max Encoder Resolution (400 pulses)

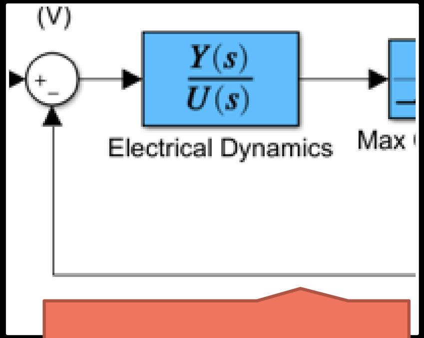
Goals

- Rise Time (< 0.017 s)
- Overshoot (< 10 %)
- Simulink Model of Motor Within 5 % Error
- Support shapes with >5 vertices
- Multi-shape animations
- Live orientation tracking

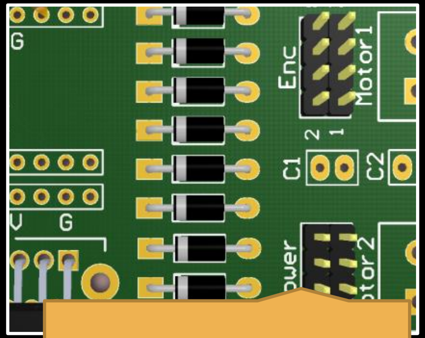
LASER LIGHT SHOW



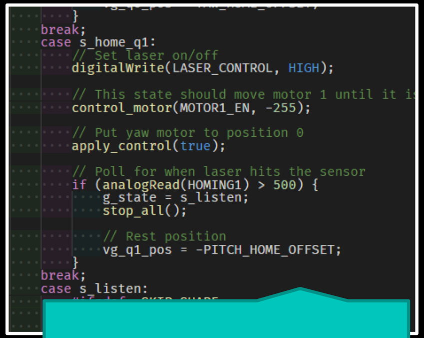
Motors



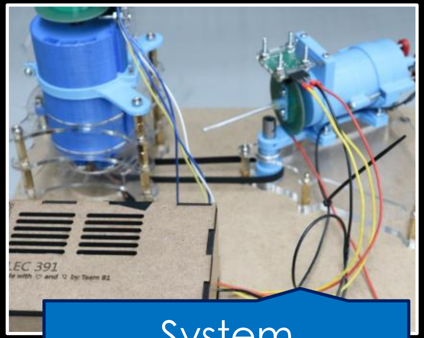
Modeling



Circuits



Controller

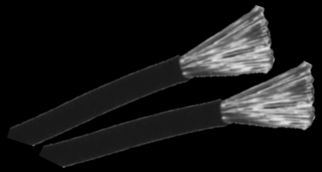


System Integration

Design and build a 2 degree of freedom spherical wrist that includes 2 mechanically commutated, permanent magnet DC motors that can draw a shape on a flat surface

MOTOR DESIGN DECISIONS

Brushes



Stranded wire
- Wears out quickly
- Flimsy

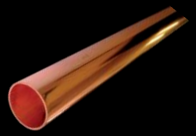
Carbon Brush
- Durable
- Large surface area to conduct current

Magnets

Circular Magnets
- Weak magnetic field
- Large quantities; light weight

60mm x 10mm x 5mm Rectangular Magnets
- Length to cover rotor core
- Strong magnetic field
- Small quantities; heavy weight

Commutator

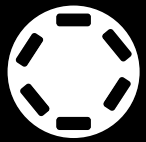


Copper Tube
- Durable
- Fixed radius
- Difficult to implement brushes

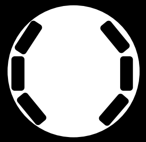
Copper Tape
- Wears out quickly
- Difficult to implement brushes

FR4 (Copper Disk)
- Durable
- Adjustable radius for the disk

Magnet Orientation

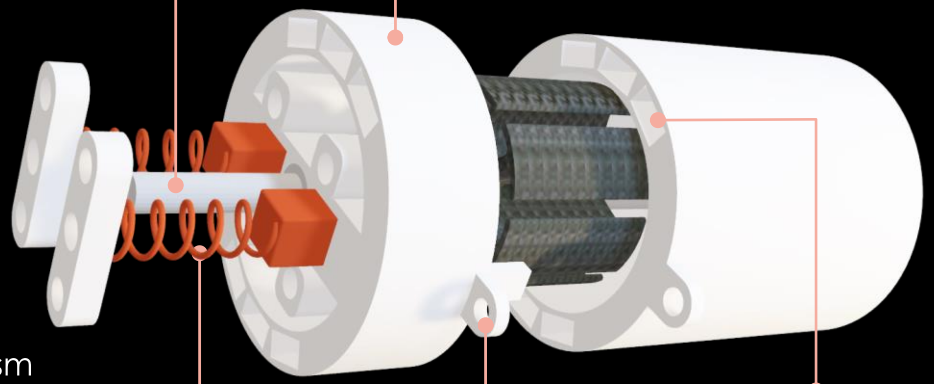


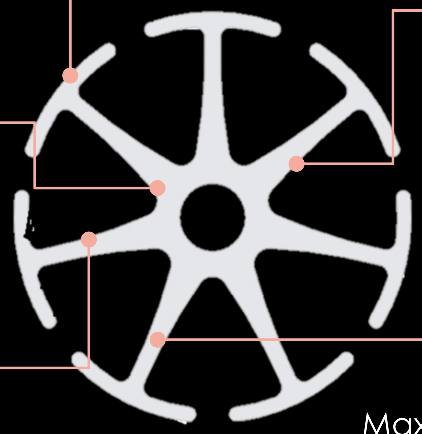
- Small magnetic flux through the rotor



- Large magnetic flux through the rotor

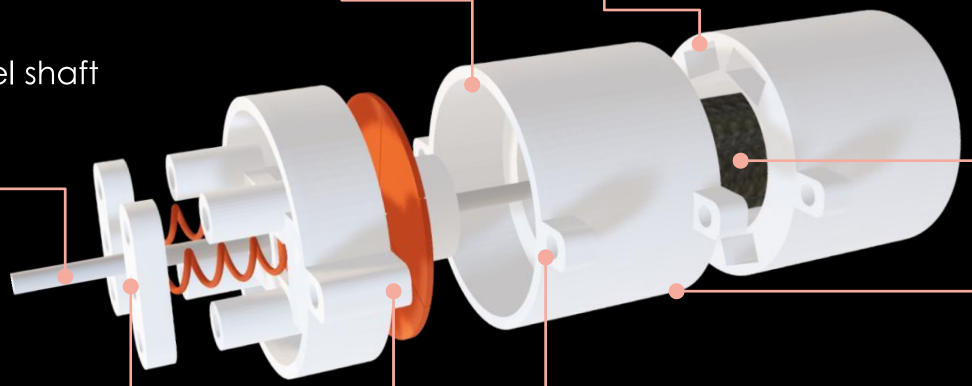
YAW MOTOR

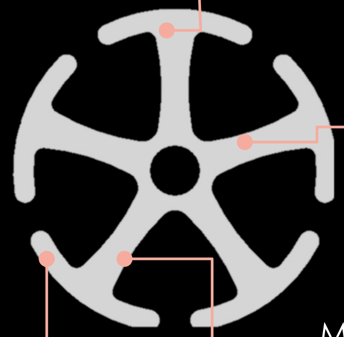

Closed casing
6.35 mm diameter steel shaft
Spring mechanism for the carbon brush
Strong connection between front & back casing using nuts/bolts
6 rectangular magnets (60mm x 10mm x 5mm)


38 mm diameter
3mm steel lamination
40 windings (26 AWG copper wire to allow higher current)
7 poles for reduced cogging with ease of winding
Maximizes torque by winding over 3 poles at a time

PITCH MOTOR

Scaled down version of yaw motor





MOTOR PARAMETERS

Kinetic Friction

Kinetic friction from $\frac{torque}{speed}$ at no load conditions

$$B = K\tau \times \frac{I_{no\ load}}{\omega_{no\ load}}$$

Torque Constant

Torque determined from conservation of power

$$V \times I = \omega \times K_\tau$$

Rotor Inertia

Calculated from mechanical time constant (time to reach 63% of final speed)

$$\tau_m = \frac{J \times R}{K\tau^2}$$

Back EMF

Back EMF calculated using KVL

$$V_{\text{measured}} - I \times R = K_v \times \omega$$

Resistance and Inductance

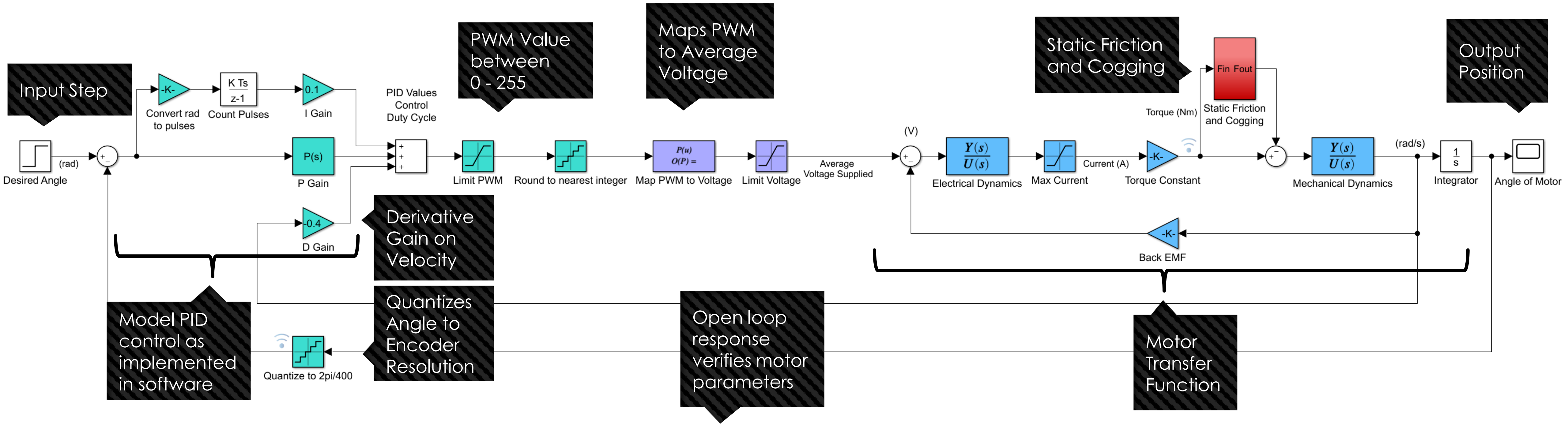
Measured using multimeter and oscilloscope

YAW

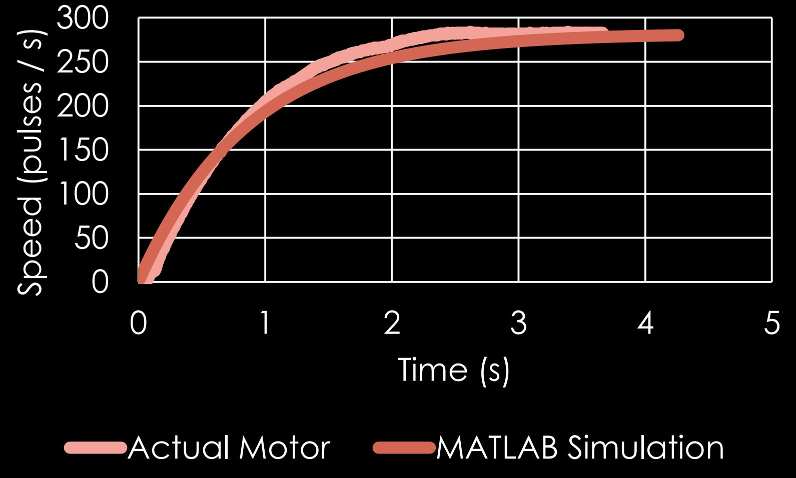
Resistance	4.18 Ω
Inductance	1.51 mH
Max Power Out	6.49 W
Torque Constant	0.00125 Nm/A
Back EMF Constant	800 rad/Vs
Inertia	0.00593 kg m^2
Kinetic Friction	6.5×10^{-6} Nm s/rad

PITCH

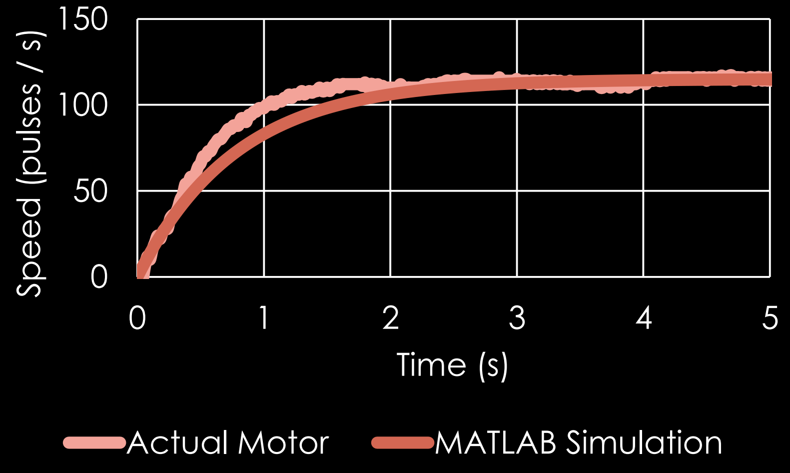
Resistance	26.7 Ω
Inductance	4.37 mH
Max Power Out	1.21 W
Torque Constant	0.02269 Nm/A
Back EMF Constant	44.077 rad/Vs
Inertia	4.11×10^{-5} kg m^2
Kinetic Friction	3.3×10^{-5} Nm s/rad



Motor 0 Open Loop Test

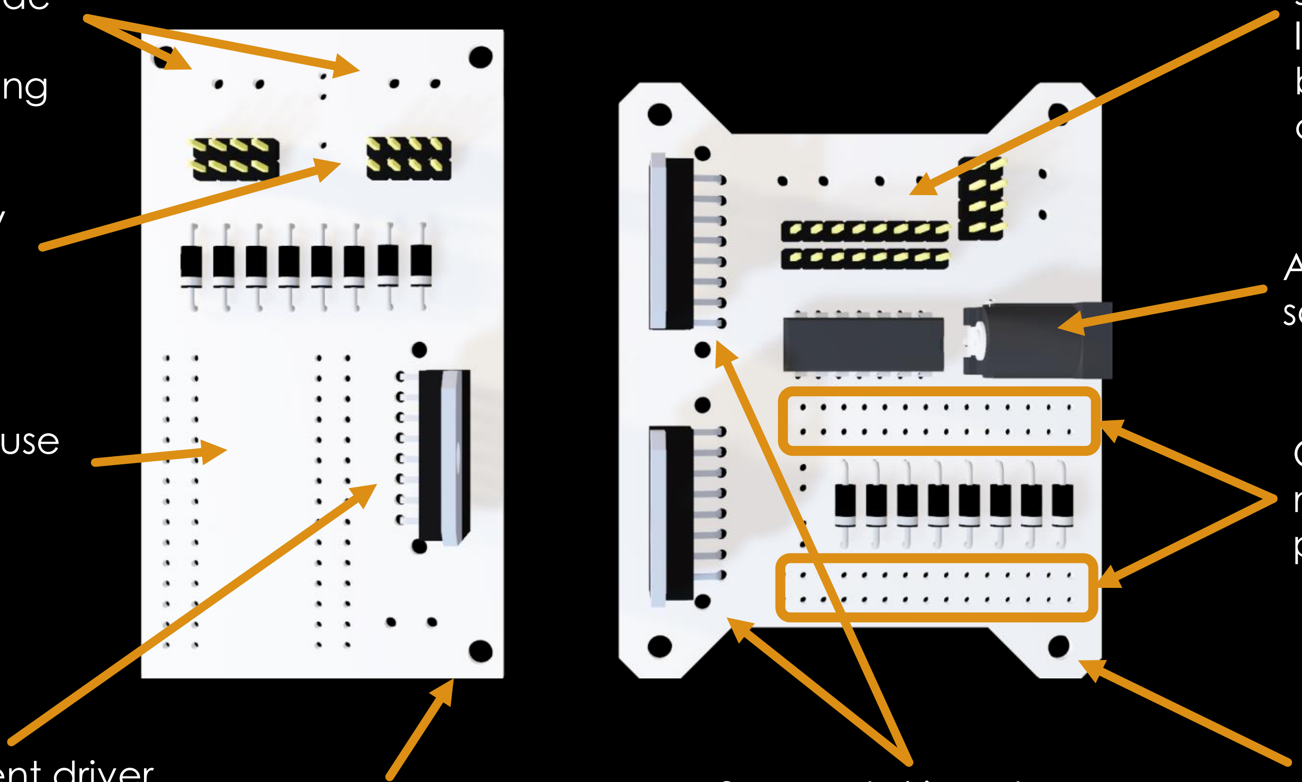


Motor 1 Open Loop Test



SIMULINK MODEL

CIRCUITS


V1
V2
Motor output on same side of PCB for neater wiring
Limited 5V pins
Inefficient use of space
Single current driver supports max 2A per motor
Inefficient placement of mounting holes
Extra 5V pins to support limit switches, external light fixtures, bypass capacitor, etc
Alternate power source
Optimized microcontroller pins mapping
Better mechanical support
2 current drivers to support higher current per motor

Pins from Encoder

- 4 pins from each encoder PCB for signals, 5V, and ground

NOT gates

- Direc1 outputted from microcontroller
- Direc2 is always inverse of Direc1

12V Input

- 12V supply for motors

Microcontroller Dock

- Maps microcontroller pins to PCB signals
- Extra header pins for access to each microcontroller pin

Diode Bridge

- Diode H-Bridge to support PWM signals to motor

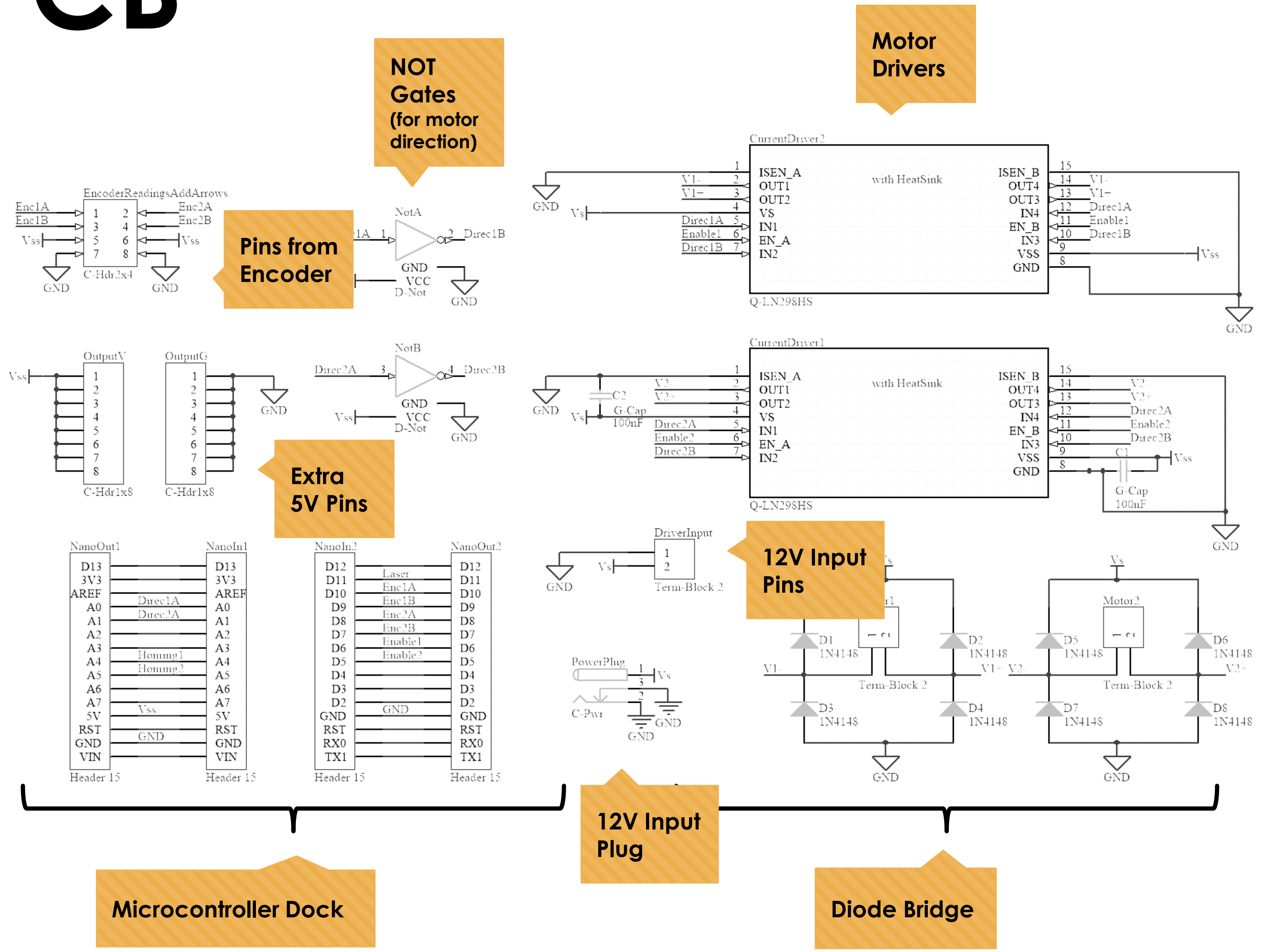
Motor Driver

- Current drivers supplying motors

Extra 5V Pins

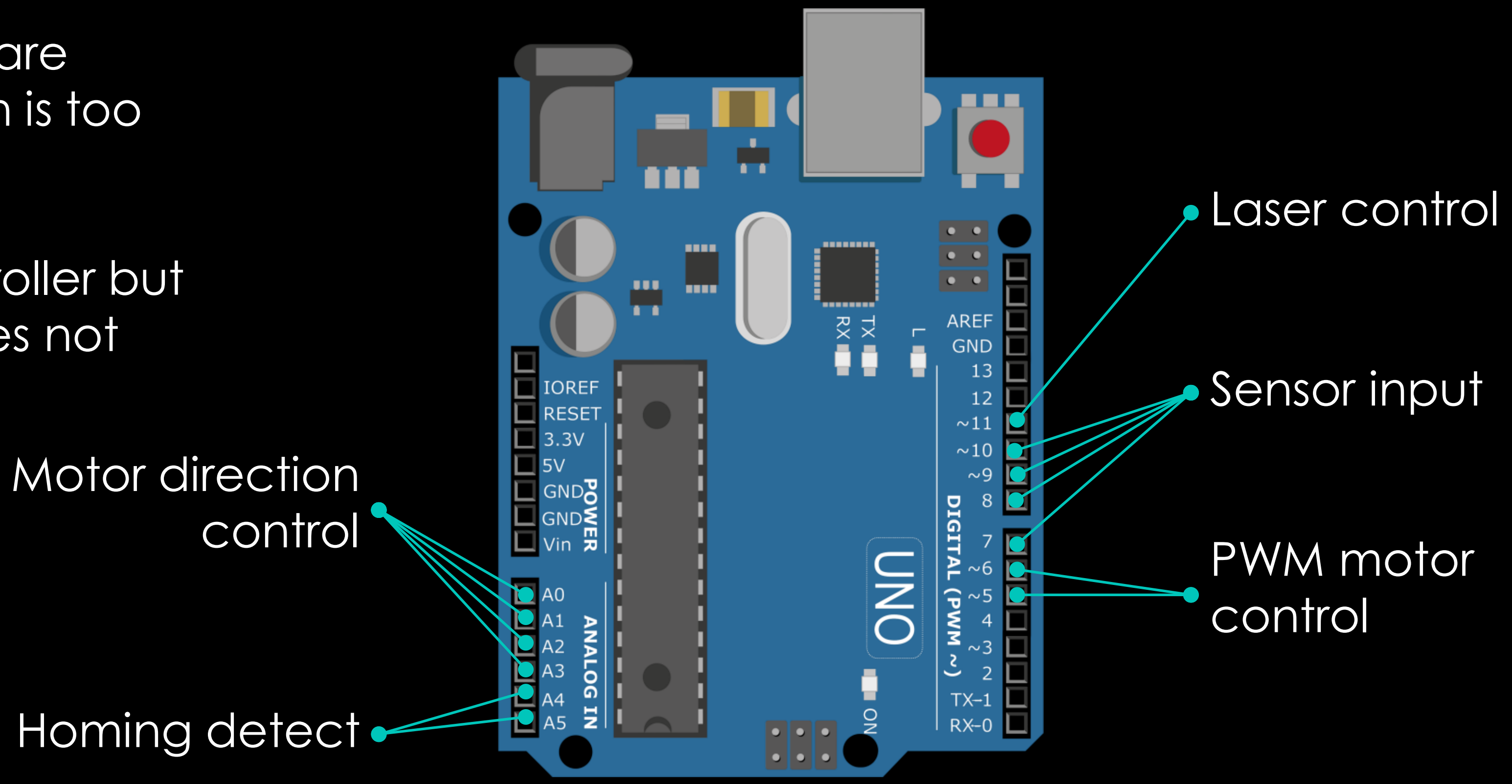
- Supplied by the microcontroller to be used for off-board components

PCB



MICROCONTROLLER

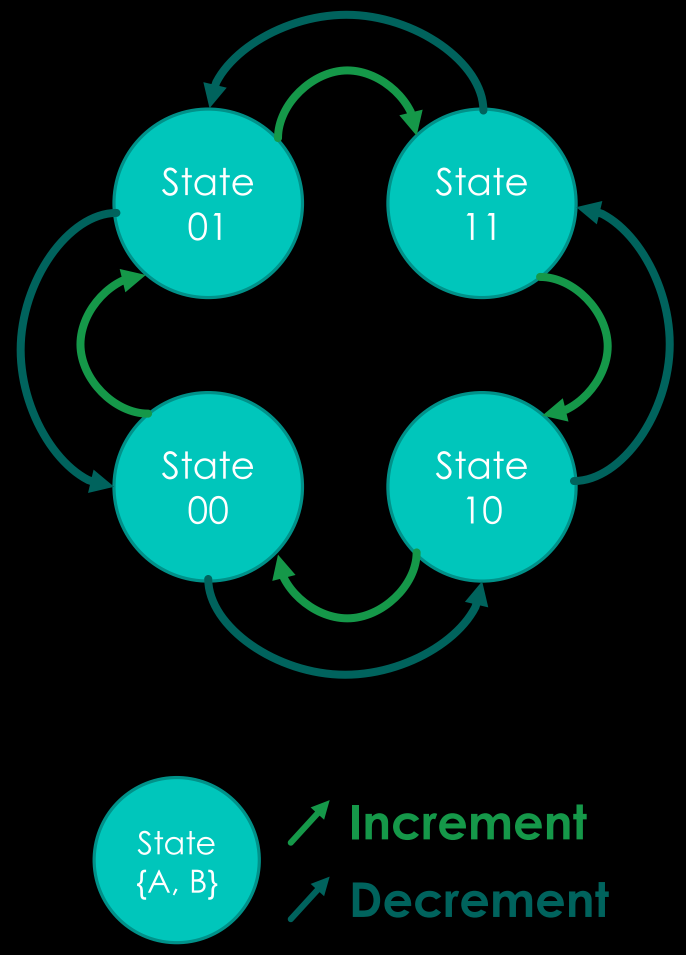
- Arduino Uno and Arduino Nano are chosen for their ease of use and safety features
- Considered using FPGA for hardware accelerated tasks but compilation is too slow and debugging is difficult ×
- Considered using 8051 microcontroller but setup is too cumbersome and does not support C++ software ×



Pin Configuration

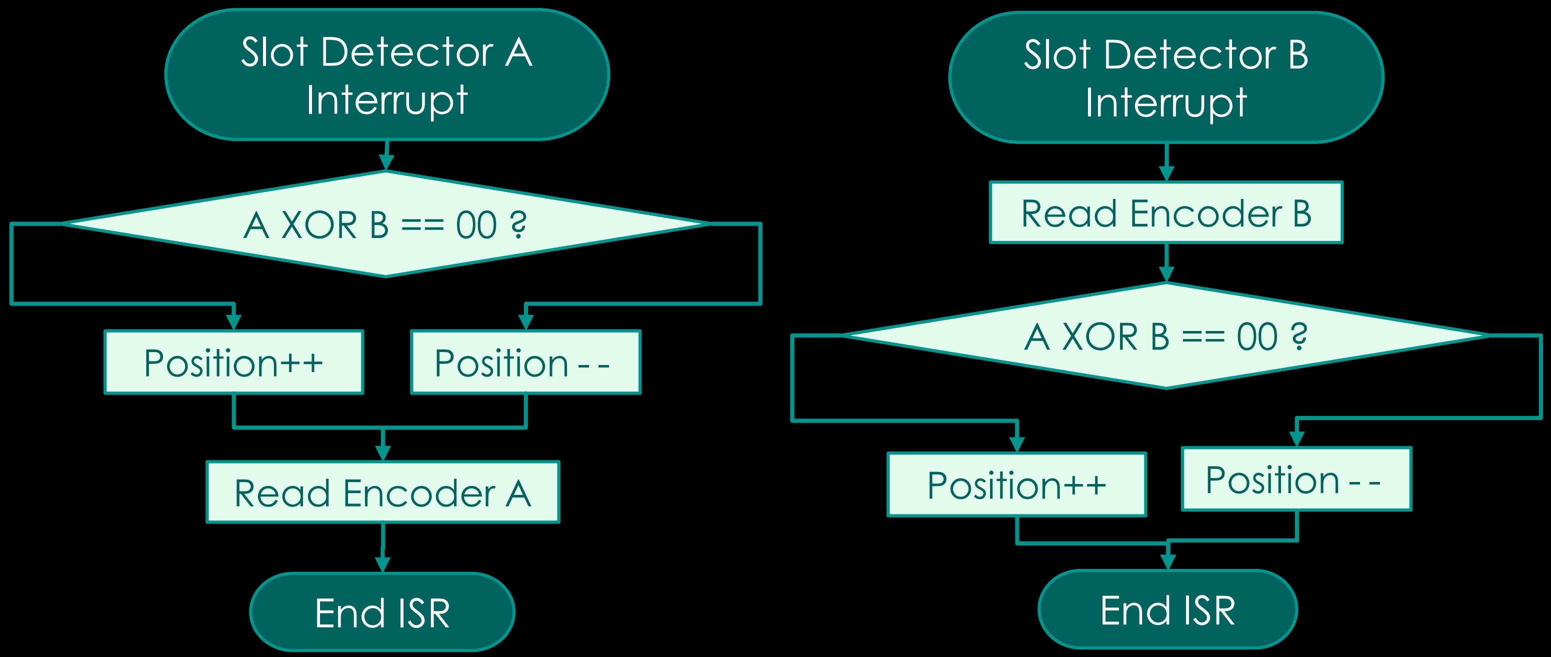
QUADRATURE DECODING

State Machine



Software Implementation

- Extremely fast ISR (4µs execution time)
- No quadrature decoder hardware needed
- Faster than using quadrature decoder



CONTROLLER LOGIC

Sensor Input

Timer ISR
1000 Hz

Proportional

Error = desired position - current position

× proportional gain

YAW	PITCH
9.81	3.60

Integral

Summation of error at control frequency

× integral gain

YAW	PITCH
0.005	0.020

Derivative

Sample speed at control frequency

× derivative gain

YAW	PITCH
-11.2	-5.00

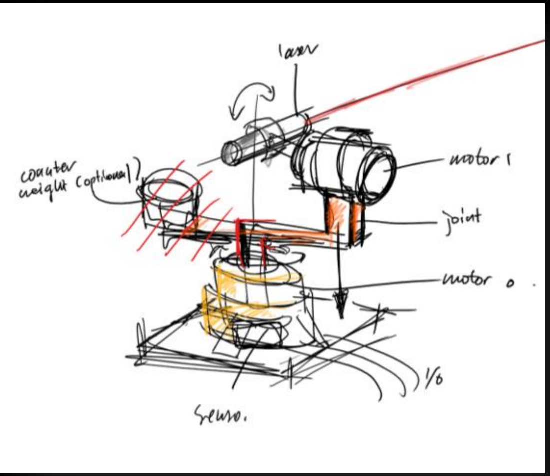
PID gains are obtained through a hybrid of model prediction and gradient descent via trial and error

+

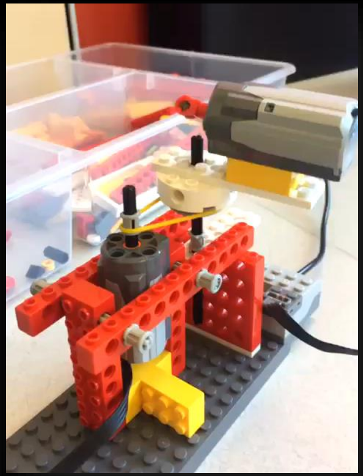
Output Logic

Execution time to control both motors is only ***180μs***!

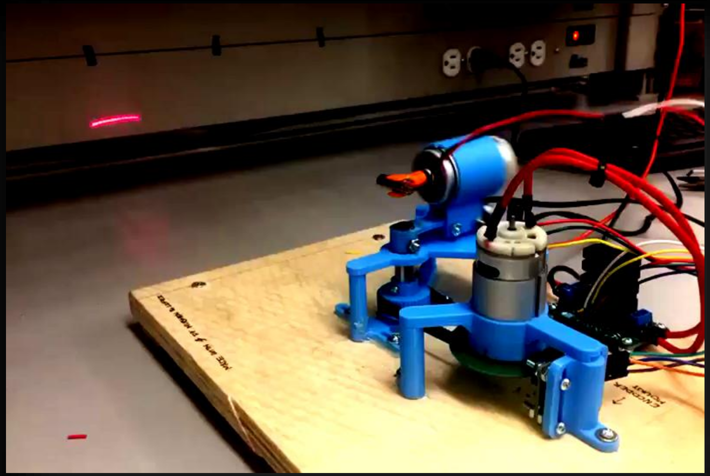
INTEGRATION PROGRESSION



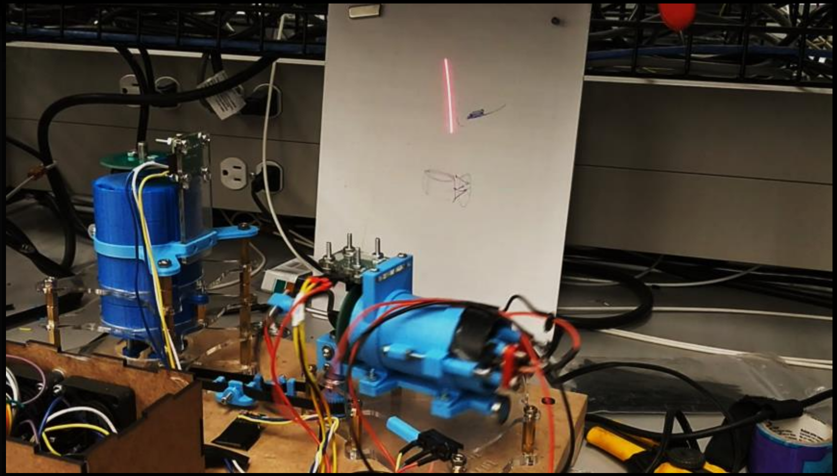
INITIAL SKETCHES



LEGO PROOF OF CONCEPT

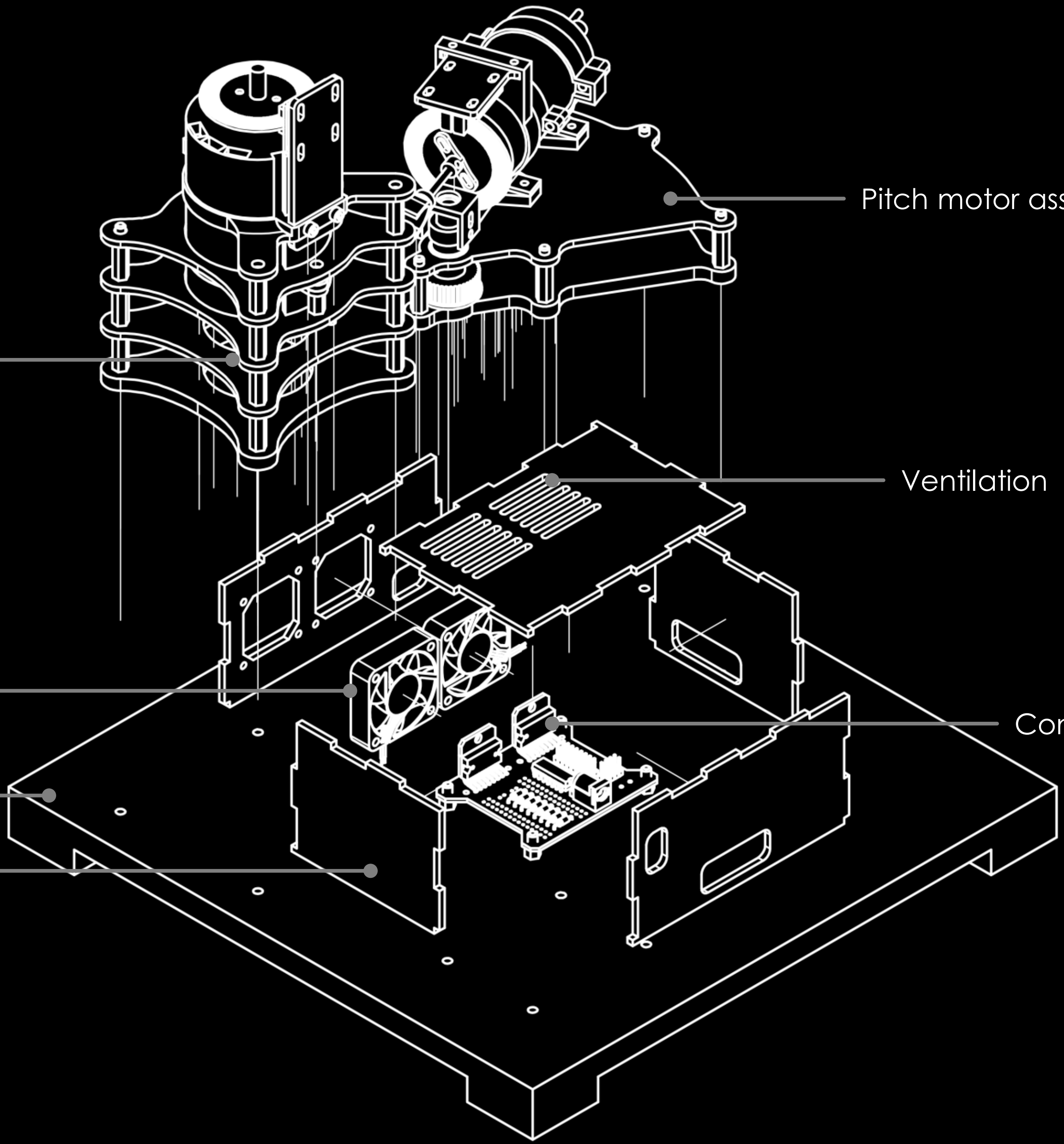


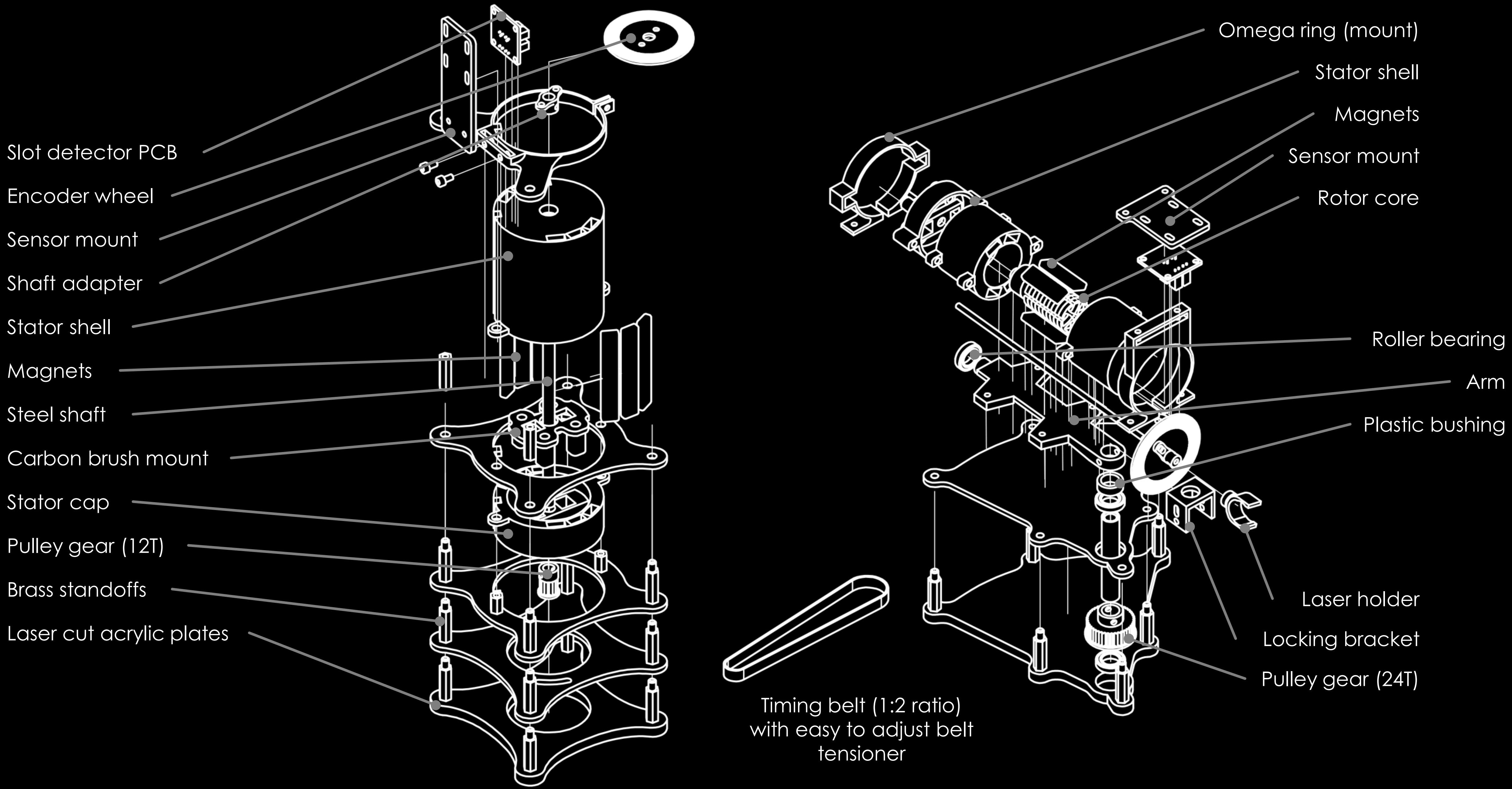
MILESTONE II RESULT



FINAL RESULT

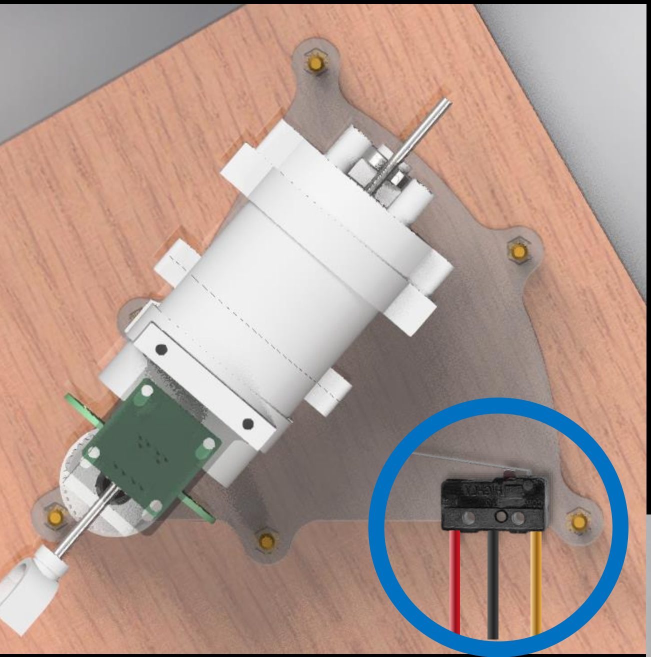
MECHANICAL FEATURES





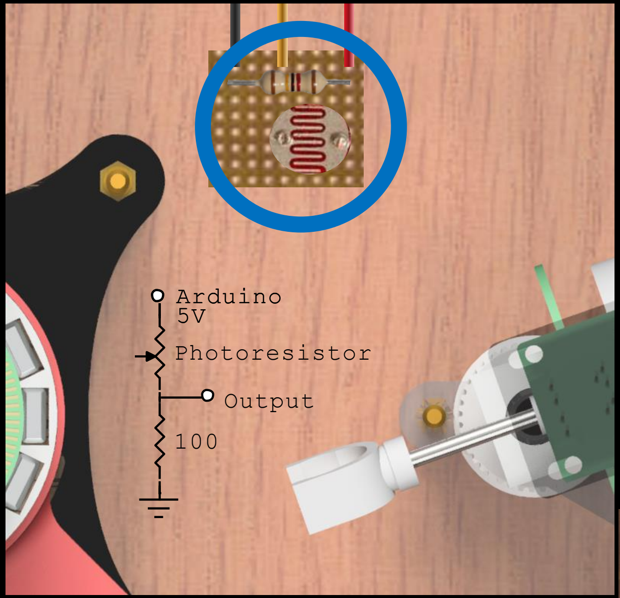
INTEGRATION

EXTERNAL CONTROL



◄ HOMING 1

- Limiter switch at platform edge
- Triggers calibration event
- Prevents further movement of motor

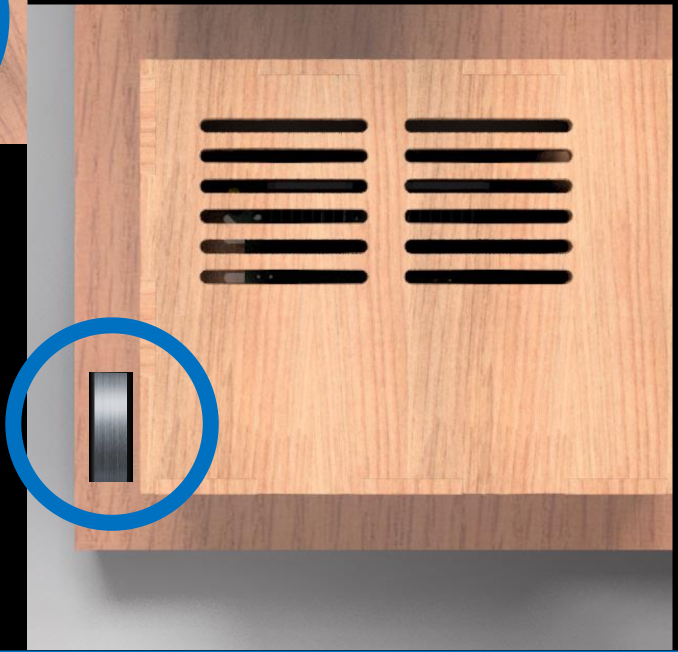


◄ HOMING 2

- Photoresistor sensor
- Resistance chosen to fit laser light
- Triggers calibration event

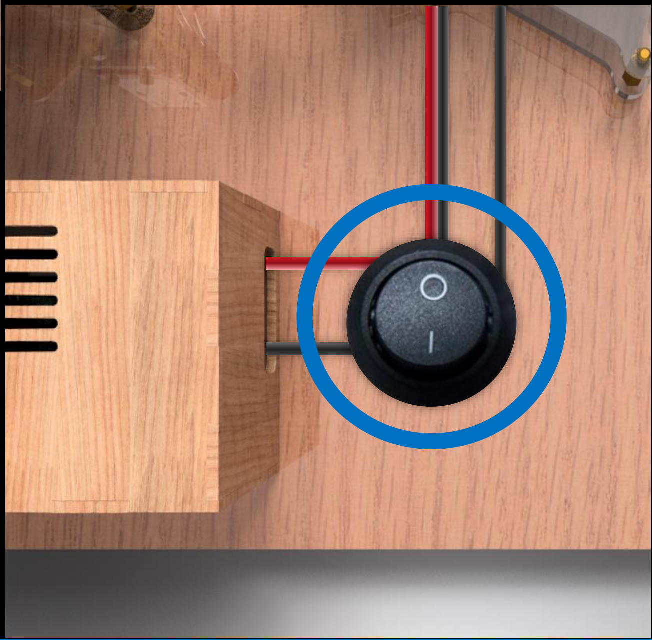
RESET SWITCH ►

- Resets controller
- Easily accessible
- Safety switch

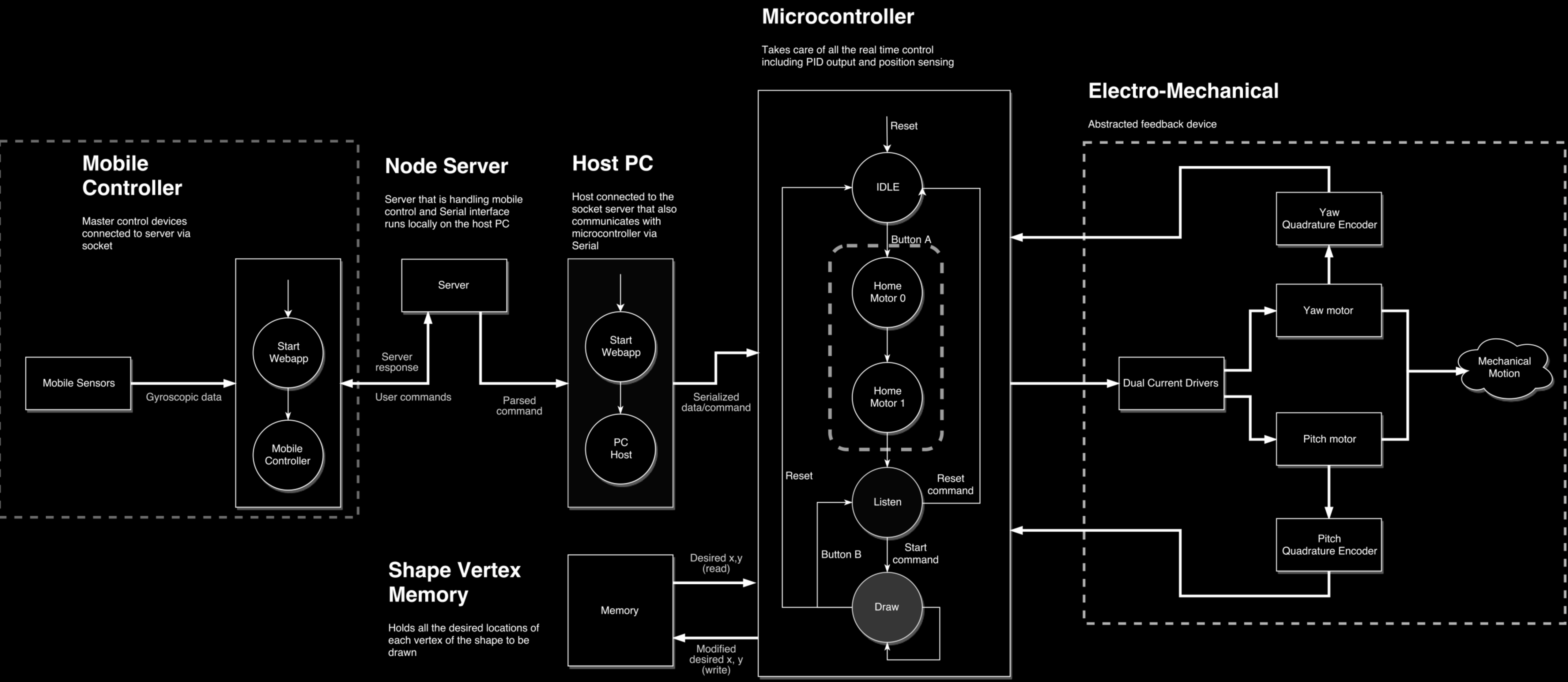


► LASER SAFETY SWITCH

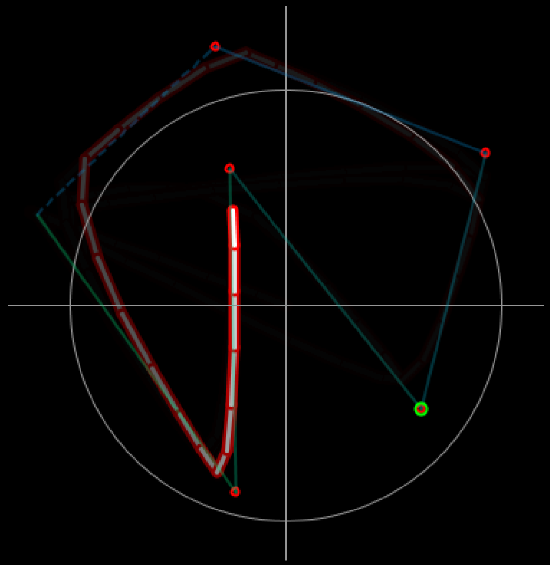
- Overrides laser control from controller
- Turns off laser to prevent eye damage



SYSTEM FLOWCHART



REMOTE CONTROLLER



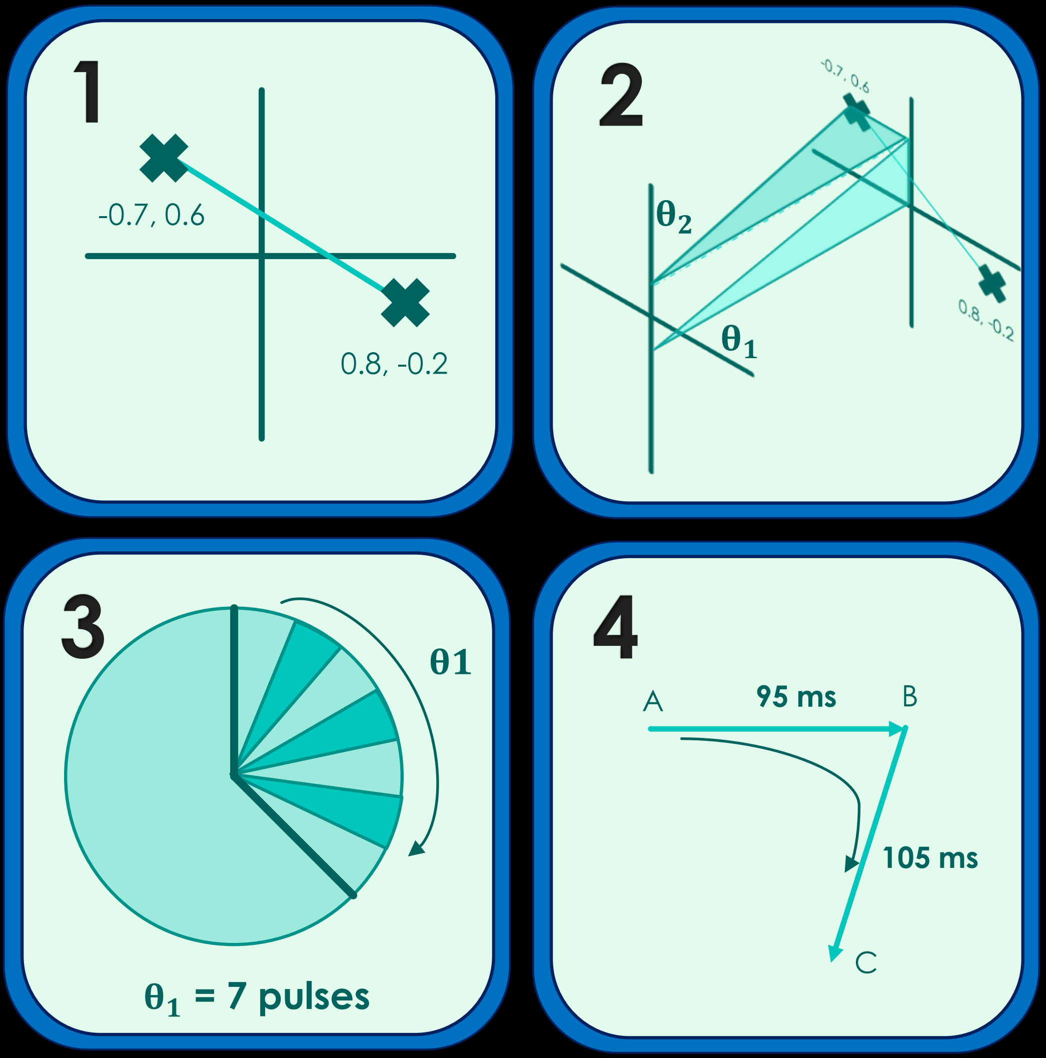
- Internet enabled device connects to the controller server via web browser
- Draw shape by tilting the device

- Host computer generates realistic laser preview
- Time vector for each vertex automatically generated
- Shape data is serialized and transmitted

- Shape data received and stored in memory
- Draws shape stored in memory at full speed

SHAPE VERTEX MAPPING

1. Map desired laser path to list of coordinates in memory (passed by host computer)
2. Inverse kinematics are applied to obtain angles
3. Angles are converted to encoder positions
4. Time vector is generated based on length of each line segment

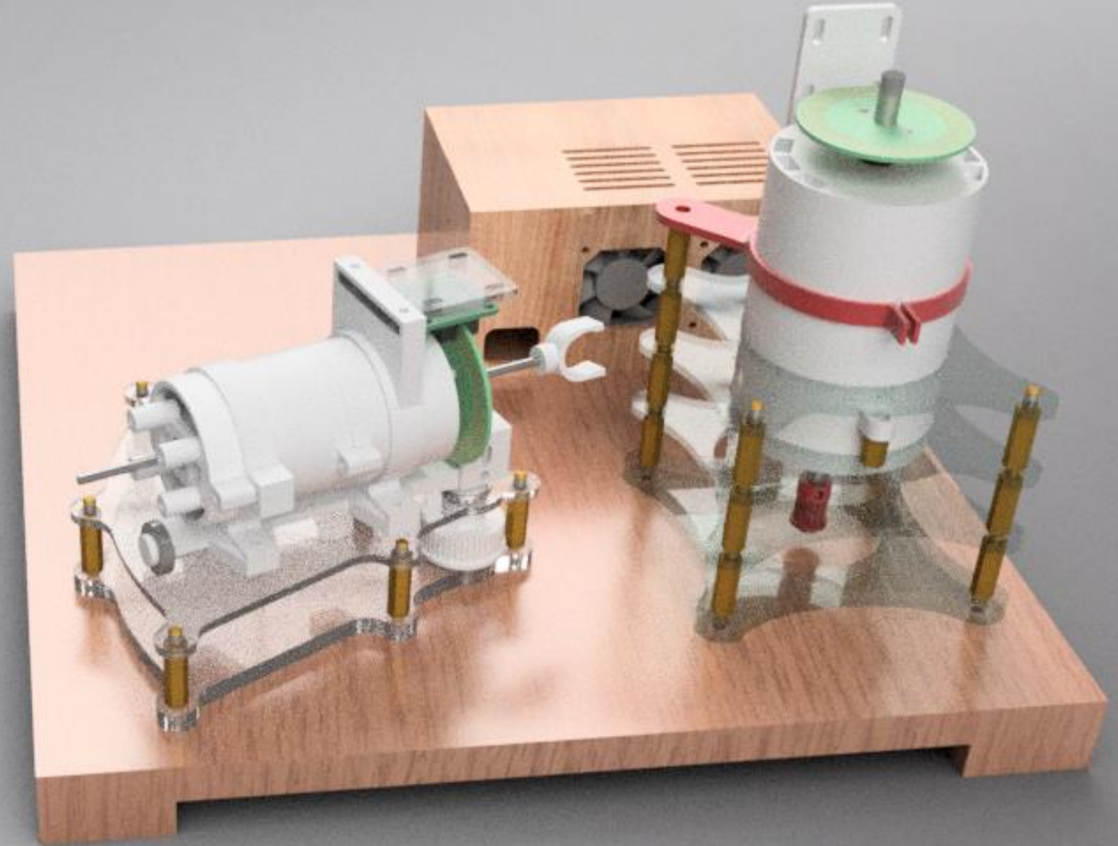


EXPORT

- **Position:** x and y are exported in two arrays of floats
- **Time Vector:** relative time between commands are exported in an array of integers
- The exported data is sent through serial and parsed in microcontroller

SUMMARY

- Fine tuned system models for the custom made motors
- Very fast and optimized controller firmware
- Capable of drawing any shapes from any internet connected device
- Integrated cooling fans
- 2:1 speed reduction with timing belt with adjustable tension



Wenoa Teves 26124157
Ou (Leo) Liu 18800152
Lufei Liu 14090154
Muchen He 44638154