Laser Light Show
MILESTILE II

ELEC 391
TEAM B1 × CONTROLLER

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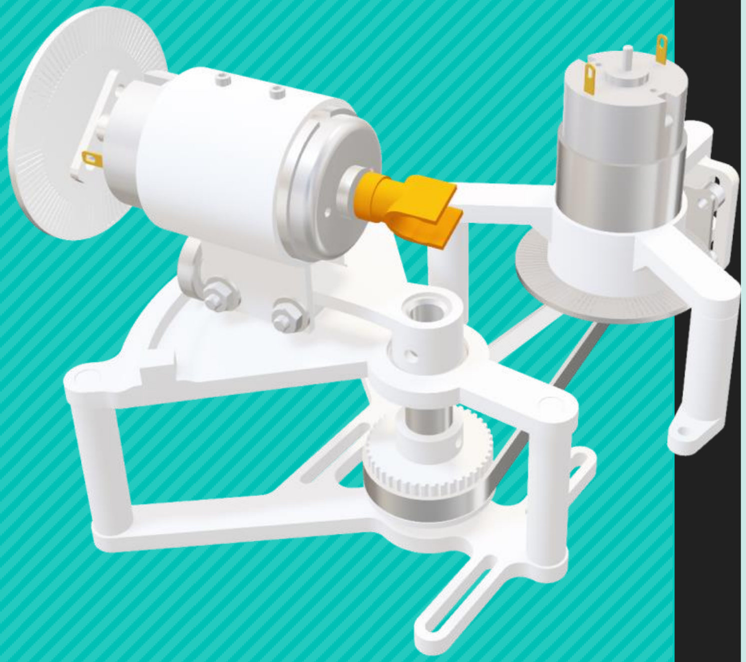
RCGs



Requirements

- Usable PID Values Obtained
- Encoder Detects All Pulses
- No Breadboards

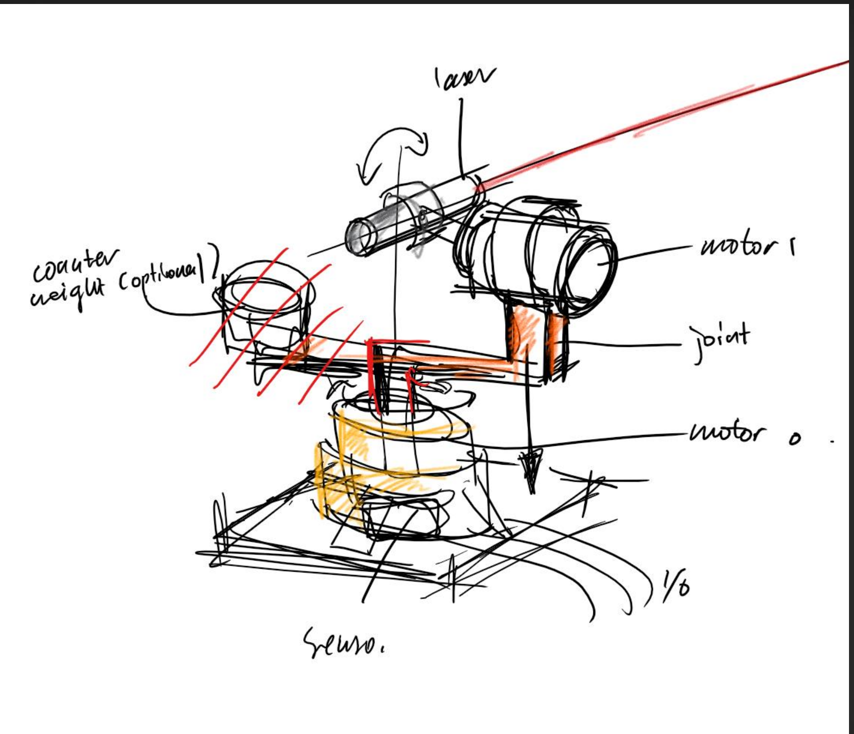
Constraints

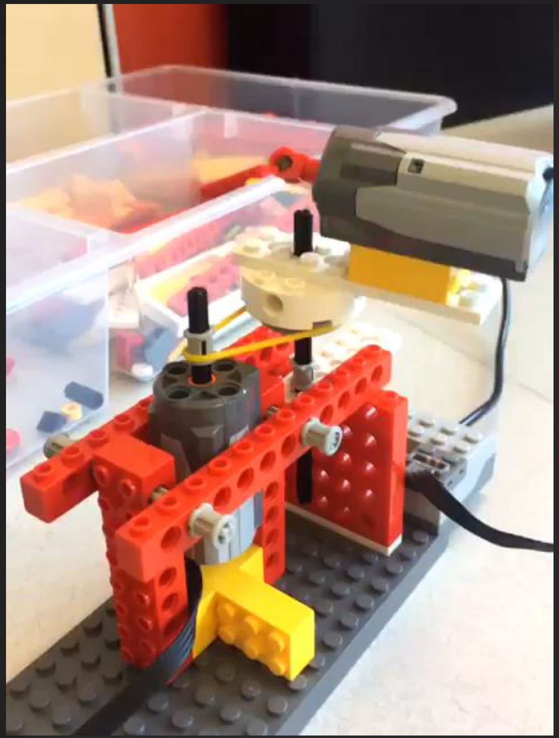
- Control Frequency of 1000 Hz
- Max Motor Current (< 2A)
- Max Encoder Resolution (400 pulses)

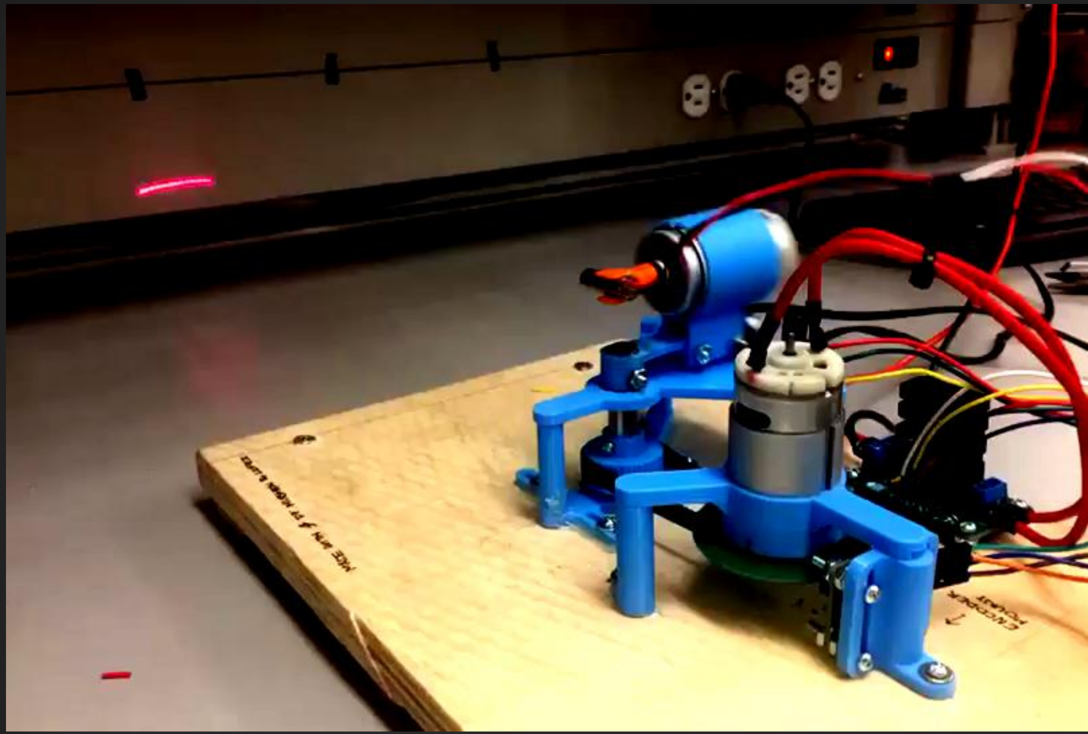
Goals

- Rise Time (< 0.017 s)
- Overshoot (< 10 %)
- Simulink Model of Motor Within 5 % Error
- Support shapes with >5 vertices

PROGRESSION







INITIAL SKETCHES

LEGO PROOF OF CONCEPT

MILESTONE RESULT

MOTOR PARAMETERS

- Resistance and Impedance
- Torque Constant
- Rotor Inertia
- Back EMF
- Kinetic Friction

R, L (8.4 Ω , 1.12mH)

Measured using multimeter and oscilloscope

Kτ ($23.54 \frac{\text{mNm}}{\text{A}}$)

Torque determined from conservation of power

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

J ($5.93 \times 10^{-6}\ \text{kg m}^2$)

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

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

Kv ($628.5 \frac{\text{RPM}}{\text{V}}$)

Back EMF calculated using KVL

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

B ($4.964 \times 10^{-6} \frac{\text{kg m}^2}{\text{s}}$)

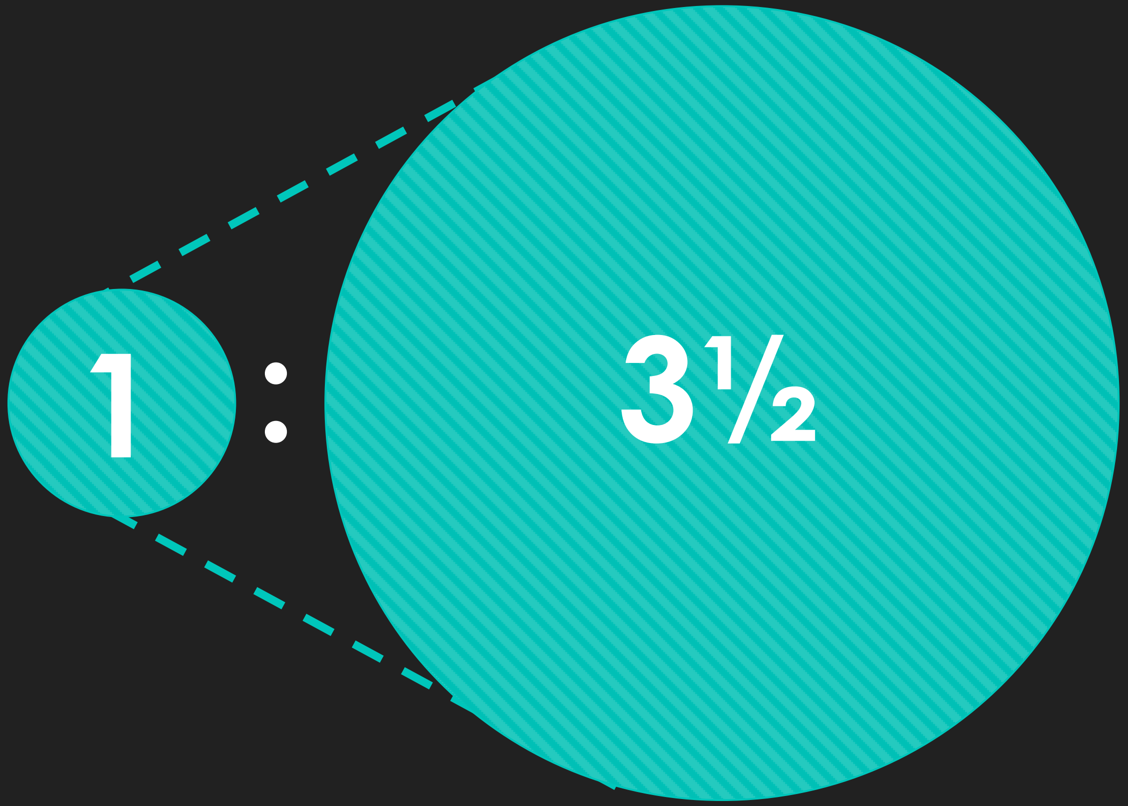
Kinetic friction from $\frac{torque}{speed}$ at no load conditions

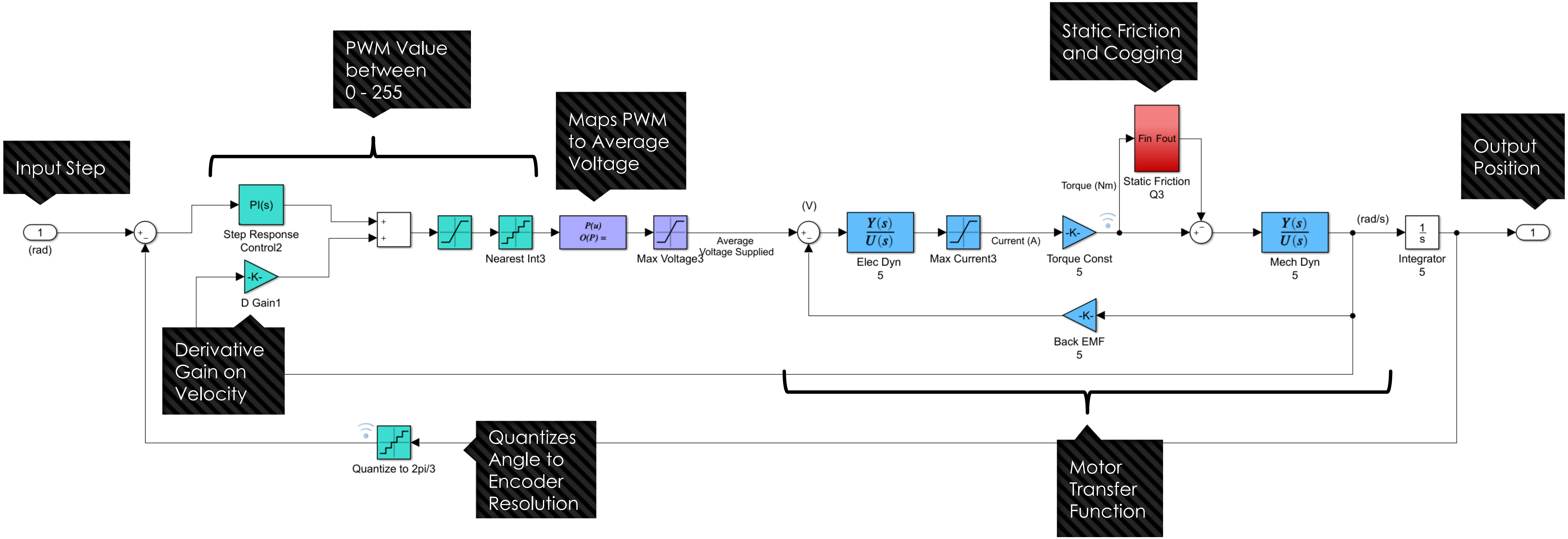
$$B = K\tau \times \frac{I_{no\ load}}{\omega_{no\ load}}$$

SPEED REDUCTION

- 1:3½ ratio
- Encoder wheel resolution increased by 3.5
- Torque increased by 3.5

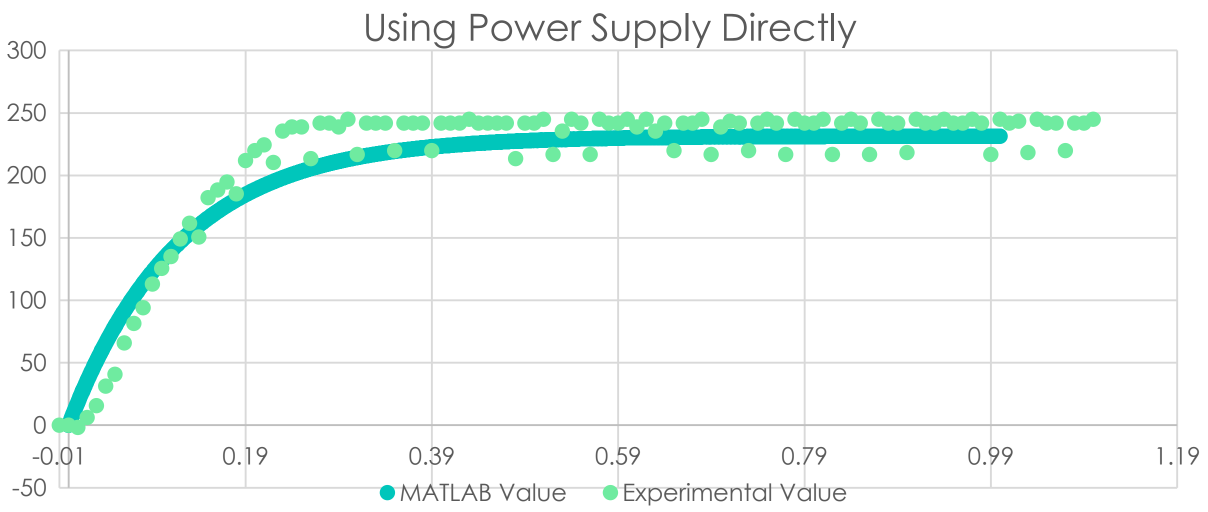
- GT2 timing belt profile
- Custom high resolution 3D printed belt drives

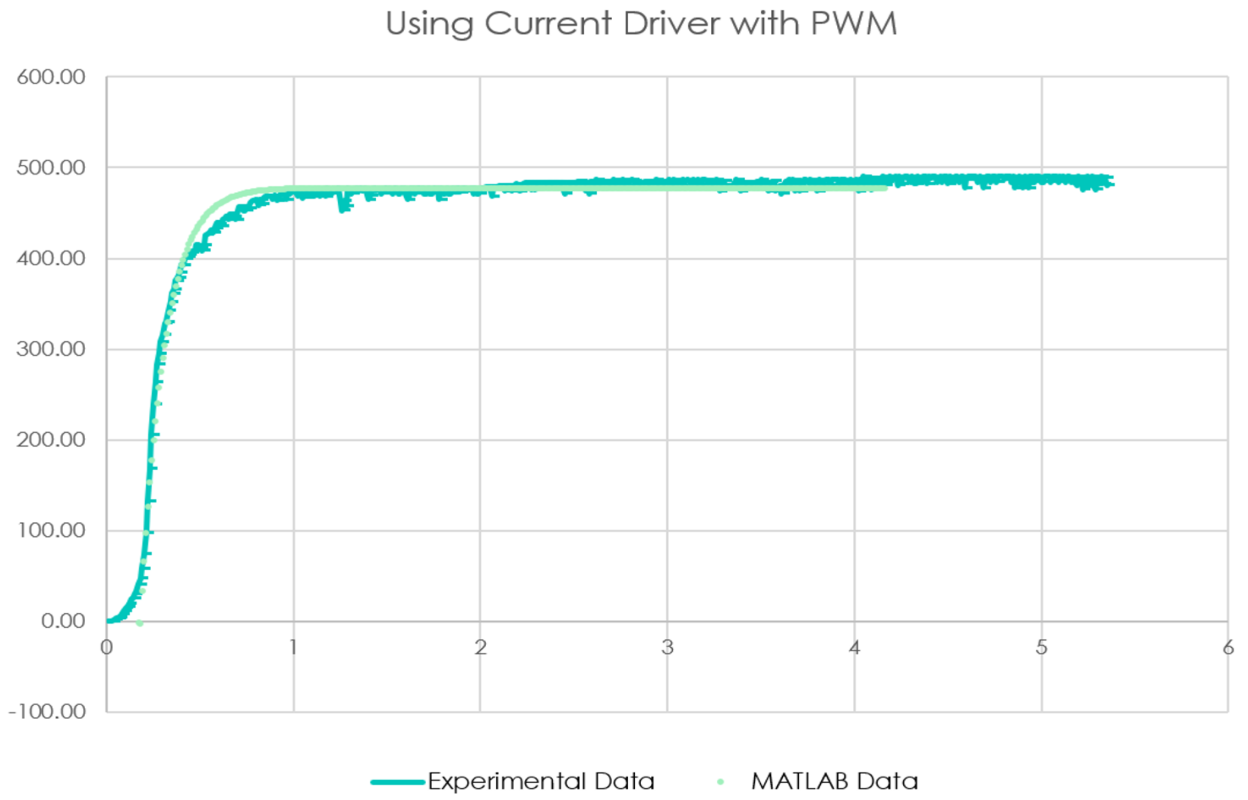




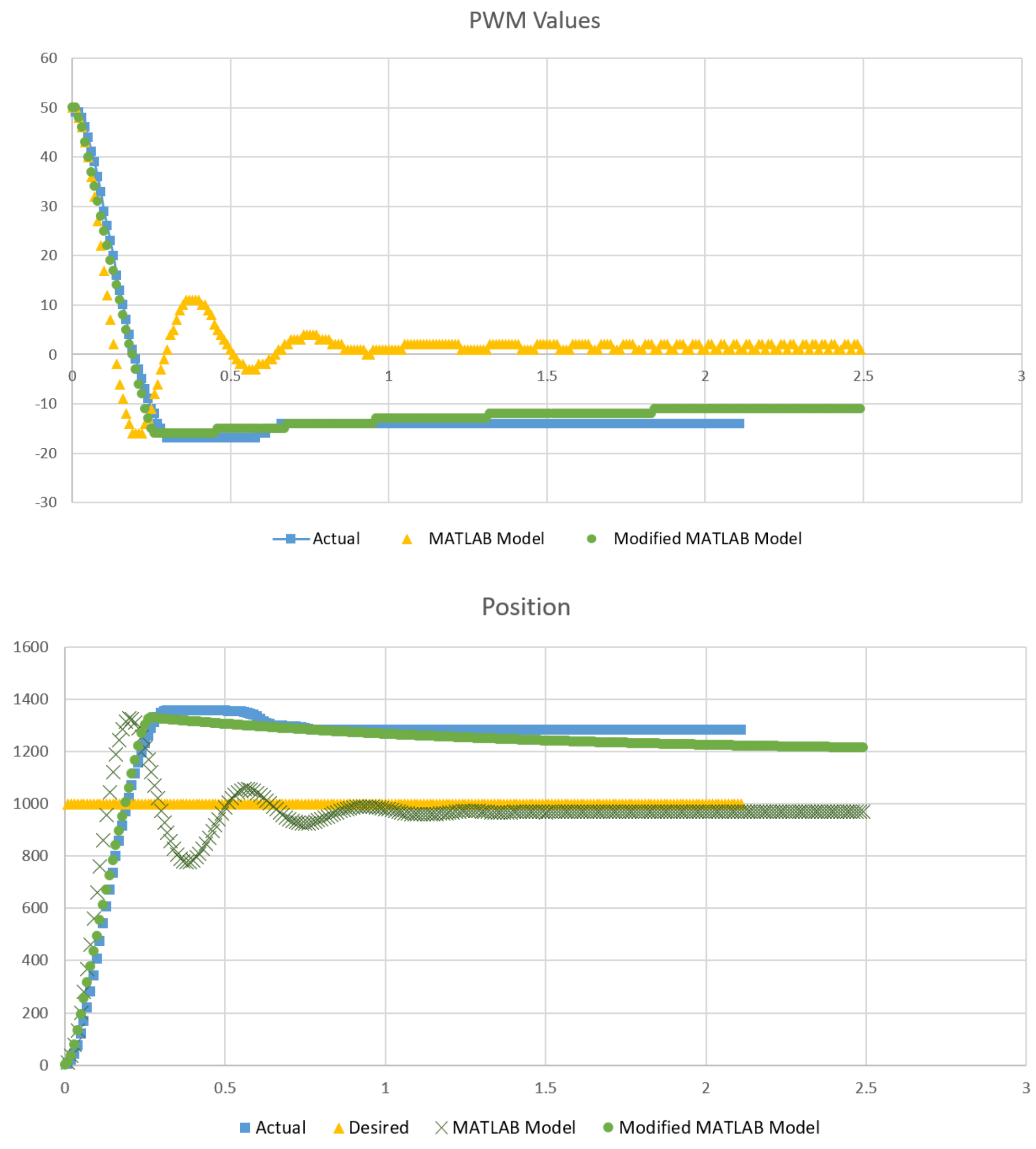
Simulink Model with PID Control

OPEN LOOP RESPONSE



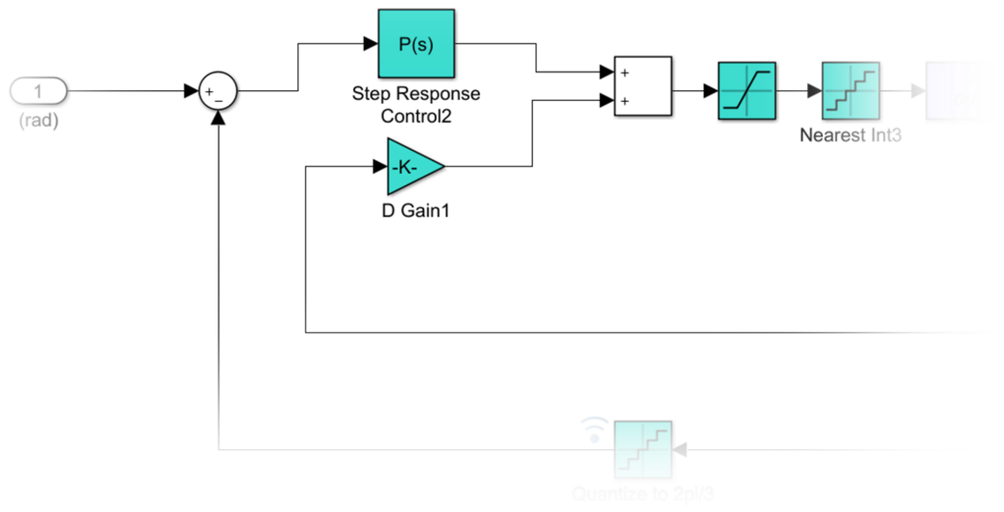


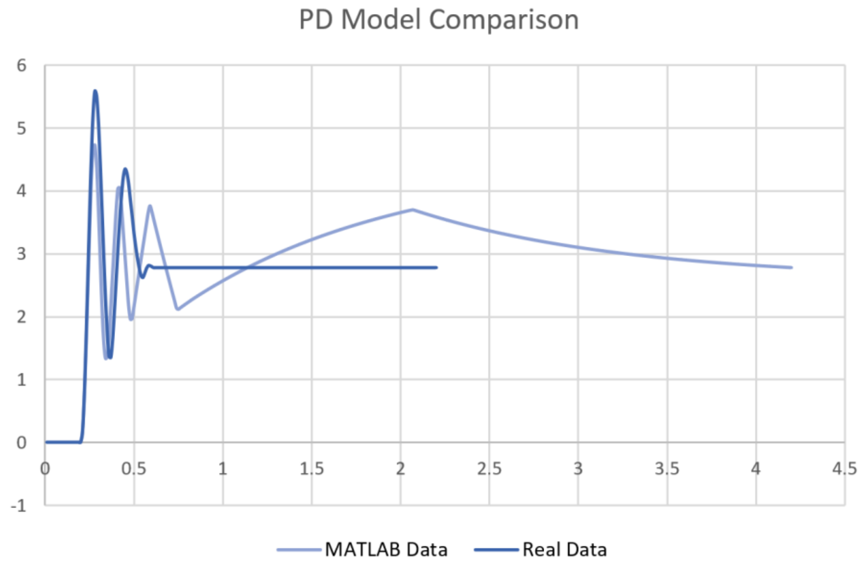
Open loop response data is used to verify adequacy of obtained motor parameters



P CONTROL

Modified MATLAB Model accounts for values of PWM less than 30 being too low to overcome cogging and static friction





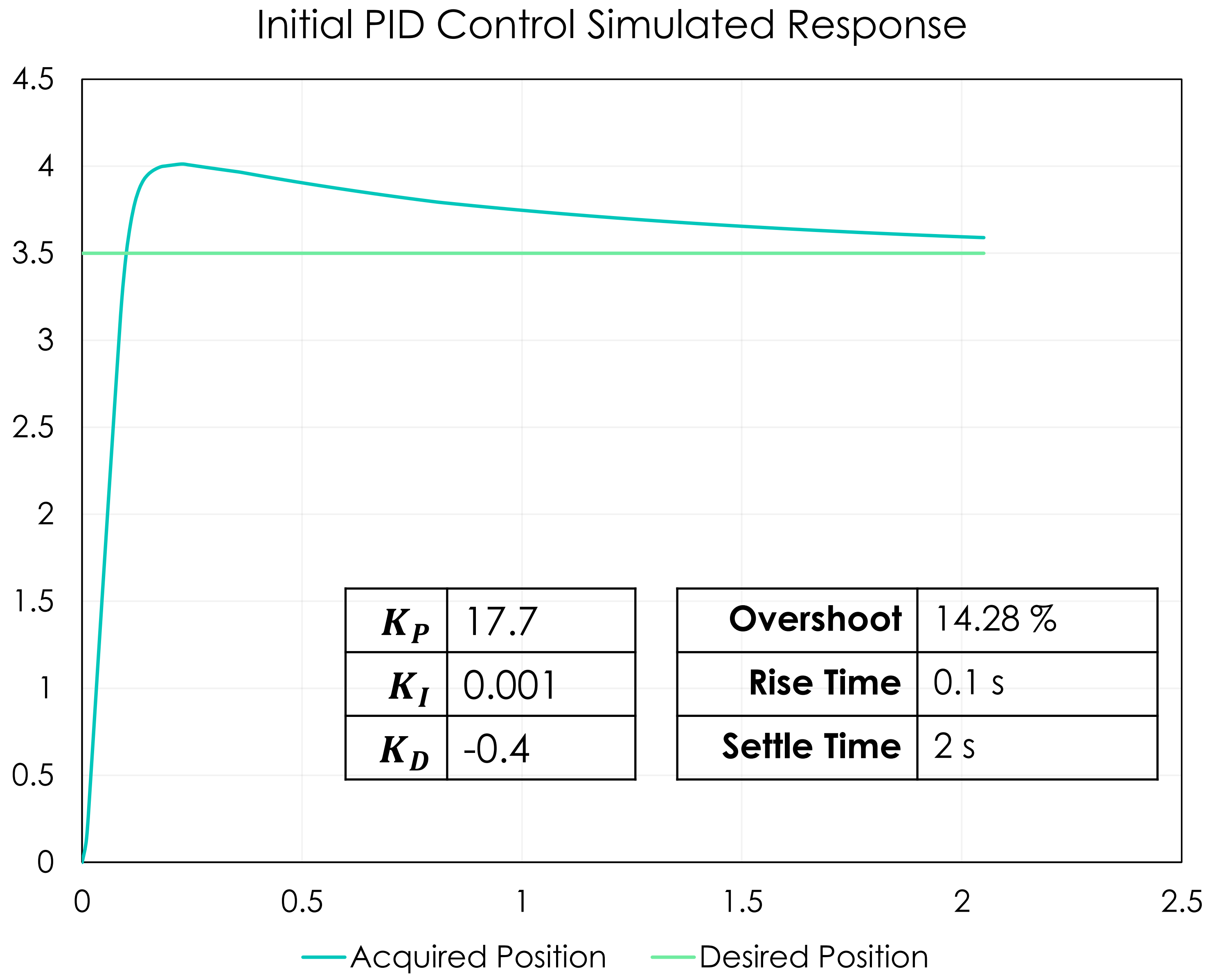
PD CONTROL

Simulink model adjusted for derivative control on current velocity instead of rate of error change

This results in a negative derivative gain

INITIAL CONTROL

- Obtained in MATLAB
- Aim for fastest rise time and small overshoot
- Ensure system is stable



K_P	17.7
K_I	0.001
K_D	-0.4

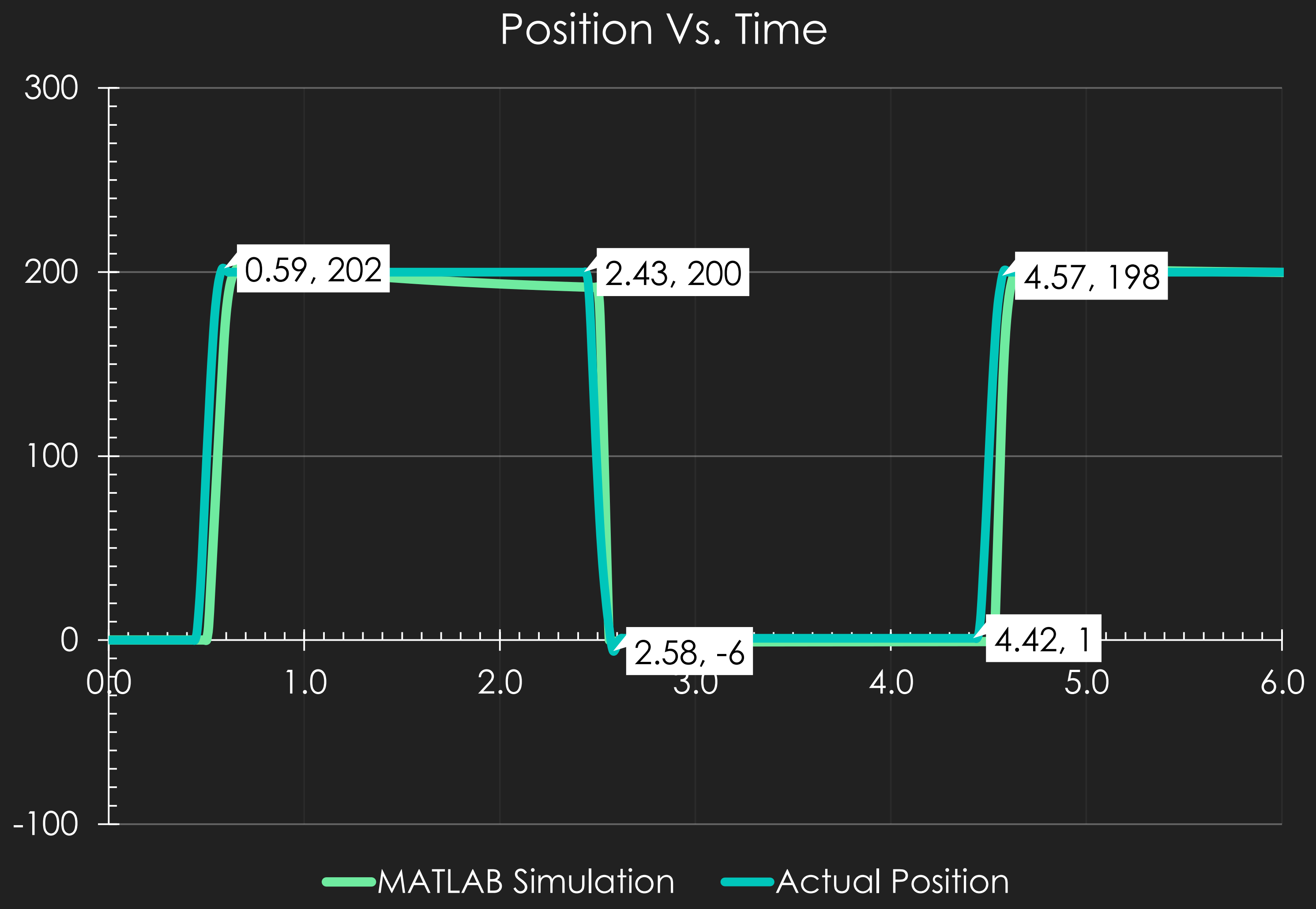
Overshoot	14.28 %
Rise Time	0.1 s
Settle Time	2 s

PERFORMANCE

- Tested on the pitch motor
- Used PID values obtained in MATLAB
- Measured performance by sampling position via controller

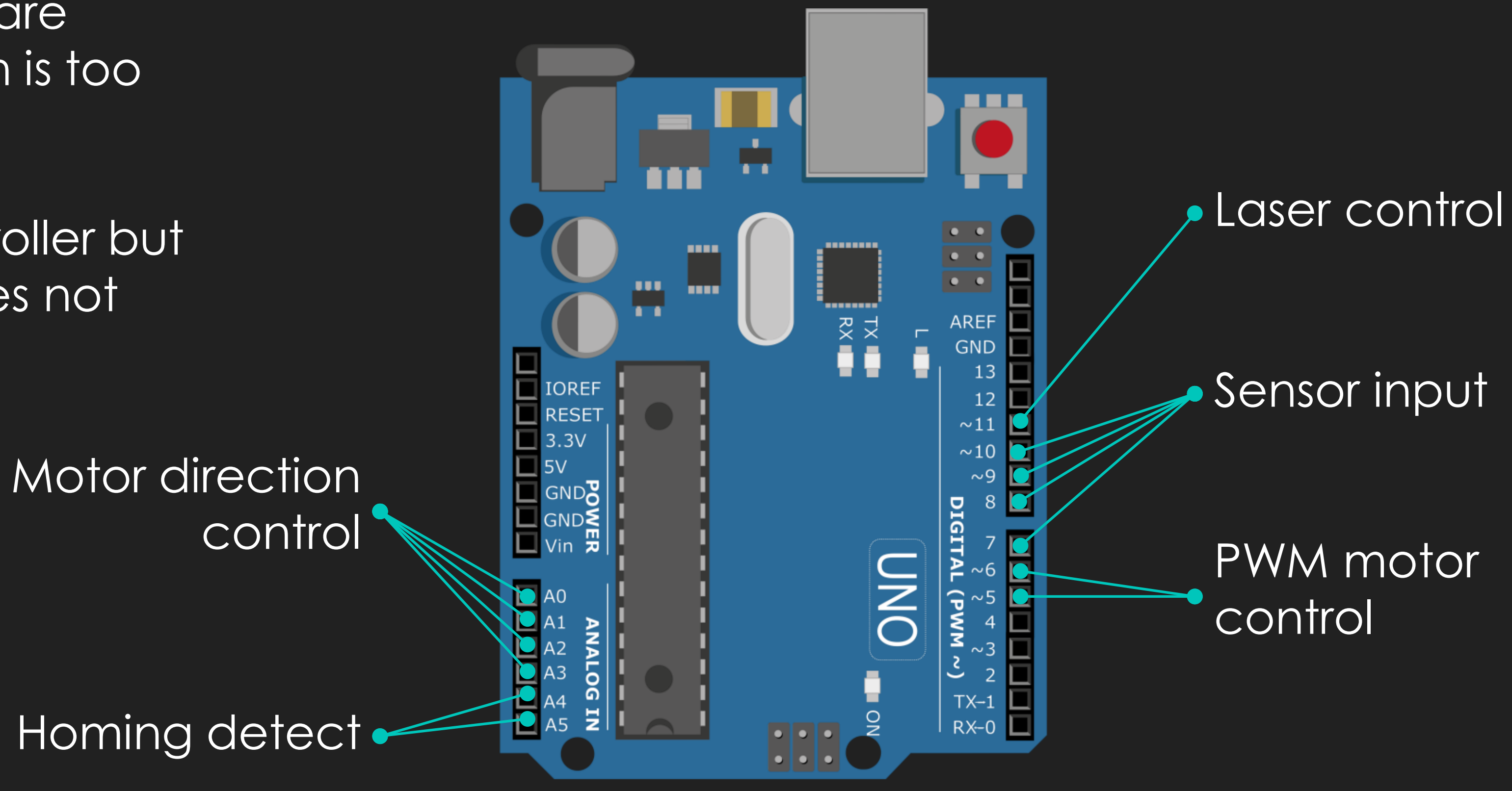
K_P	17.7
K_I	0.001
K_D	-0.4

Overshoot	2 %
Rise Time	0.15 s
Settle Time	0.12 s



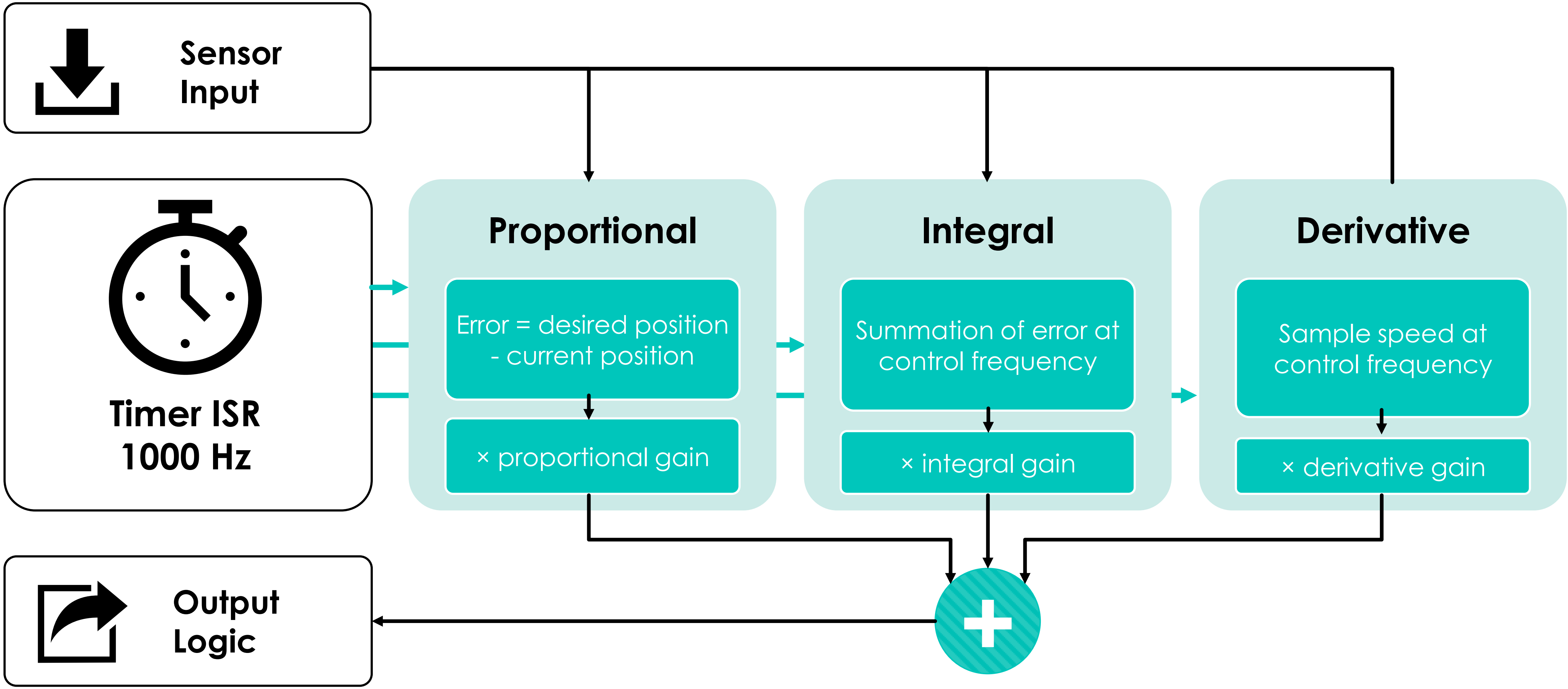
MICROCONTROLLER

- Arduino Uno and Arduino Nano is chosen for its 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 ×



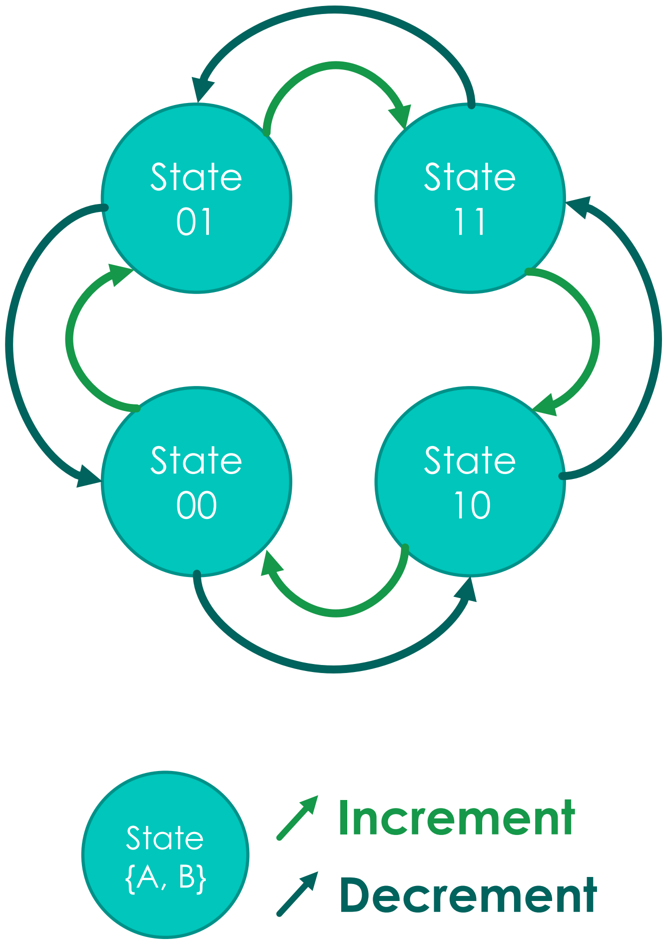
Pin Configuration

CONTROLLER LOGIC



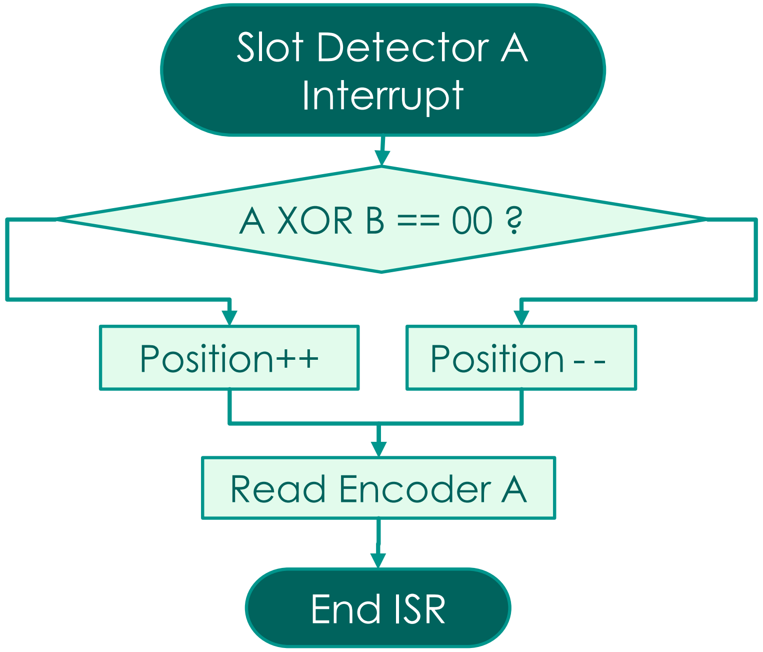
QUADRATURE DECODING

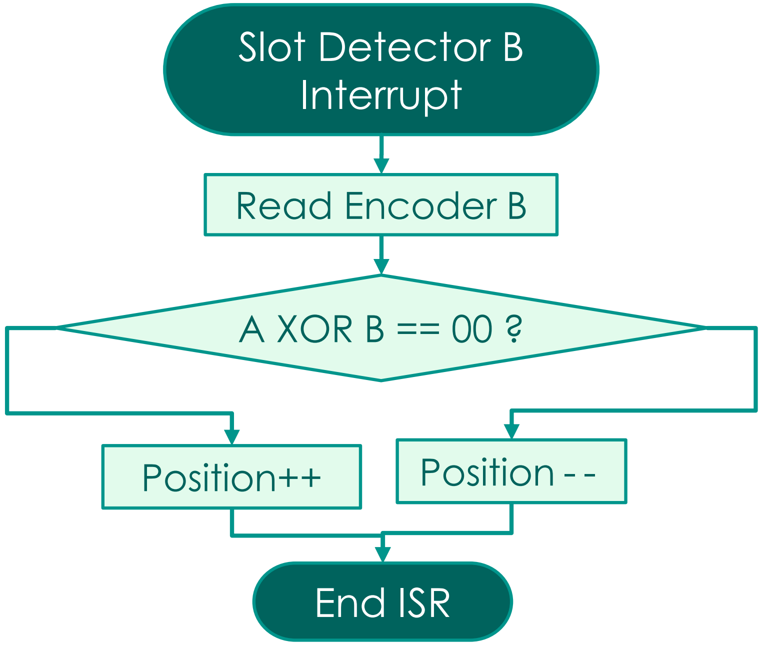
State Machine

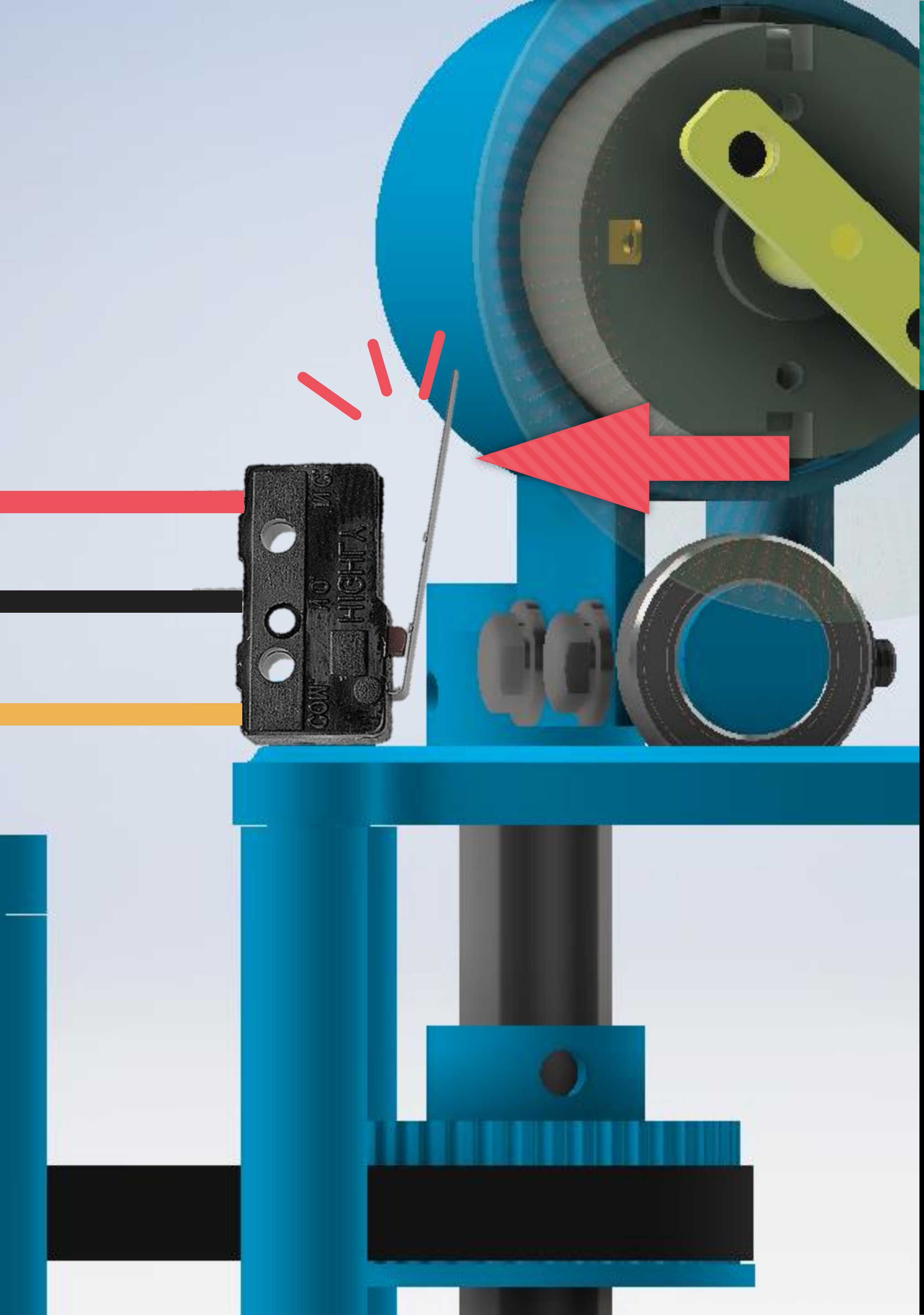


Software Implementation

- Extremely fast ISR
- No quadrature decoder hardware needed
- Faster than using quadrature decoder







POSITION HOMING

- Installed limit switch at the end
- Trigger event is done by polling at the start
- Reliable position reset routine

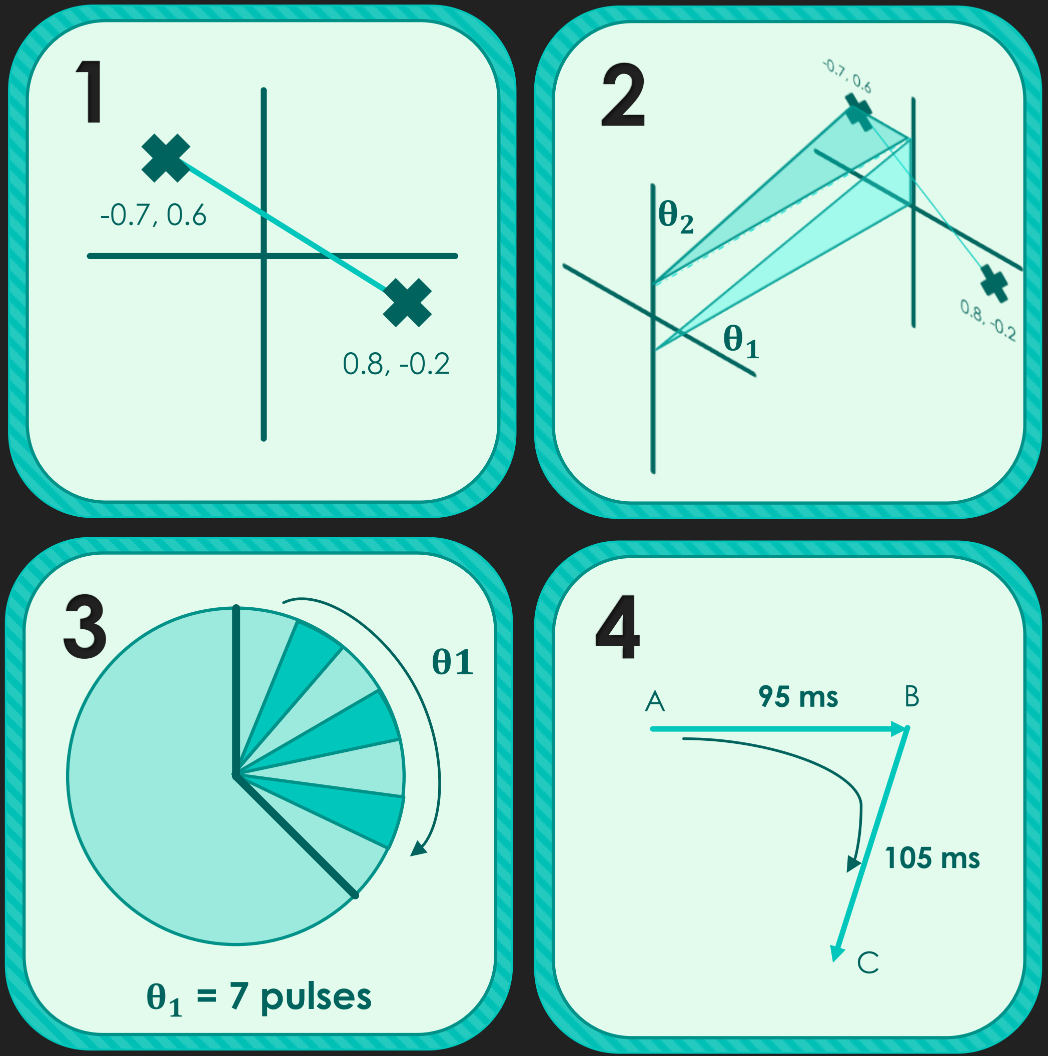
Move motor until switch is triggered

Stop and reset motor home position

Proceed to normal operation

SHAPE VERTEX MAPPING

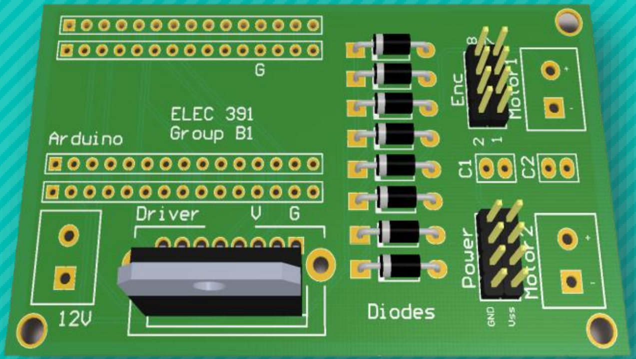
1. Map desired laser path to list of coordinates in custom-written software
2. Inverse kinematics are applied to obtain angles
3. Angles are converted to encoder positions
4. Time vector is generated based on length of each line segment



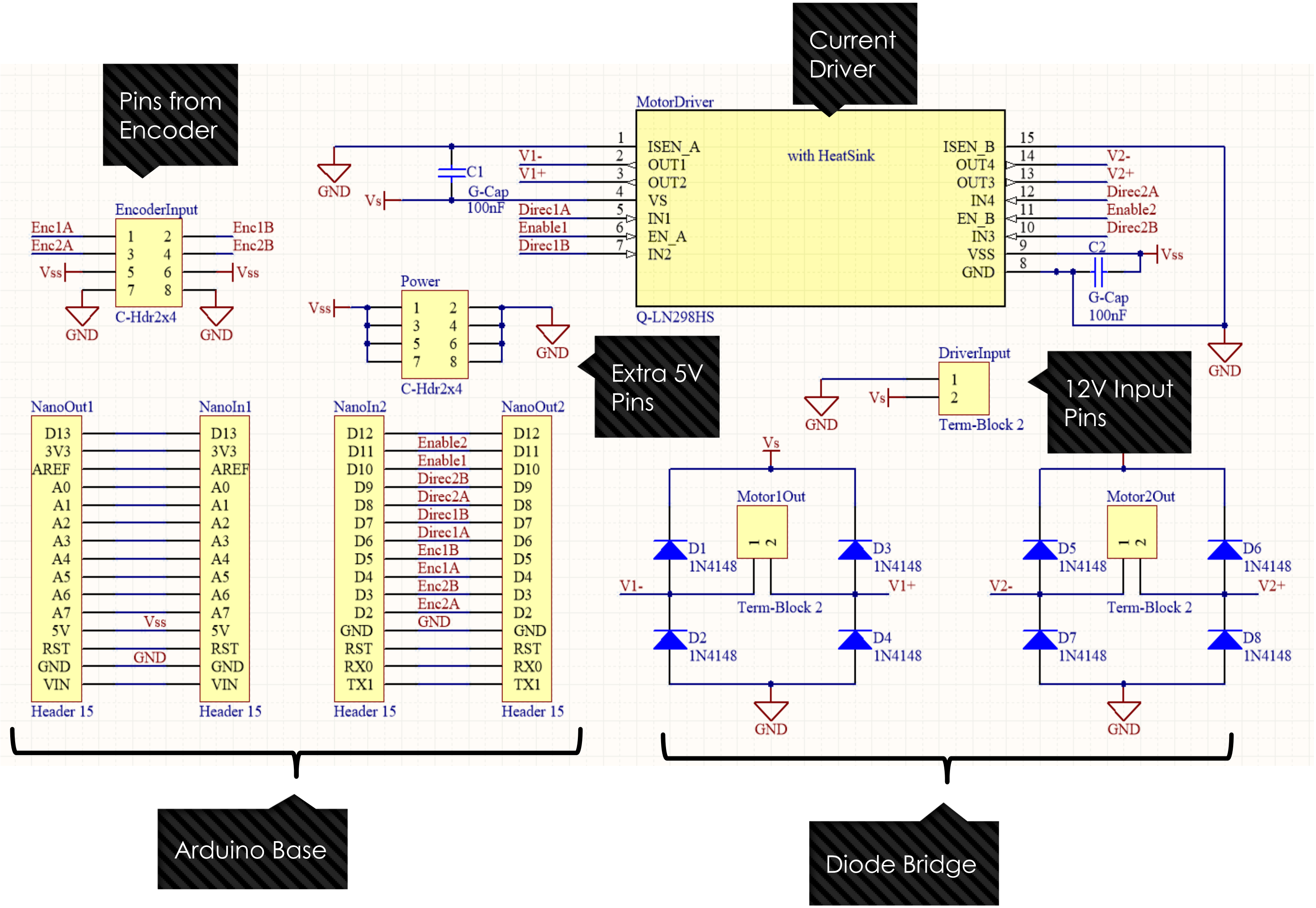
EXPORT

- **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 in a .h file compiled to the controller

SYSTEM PCB

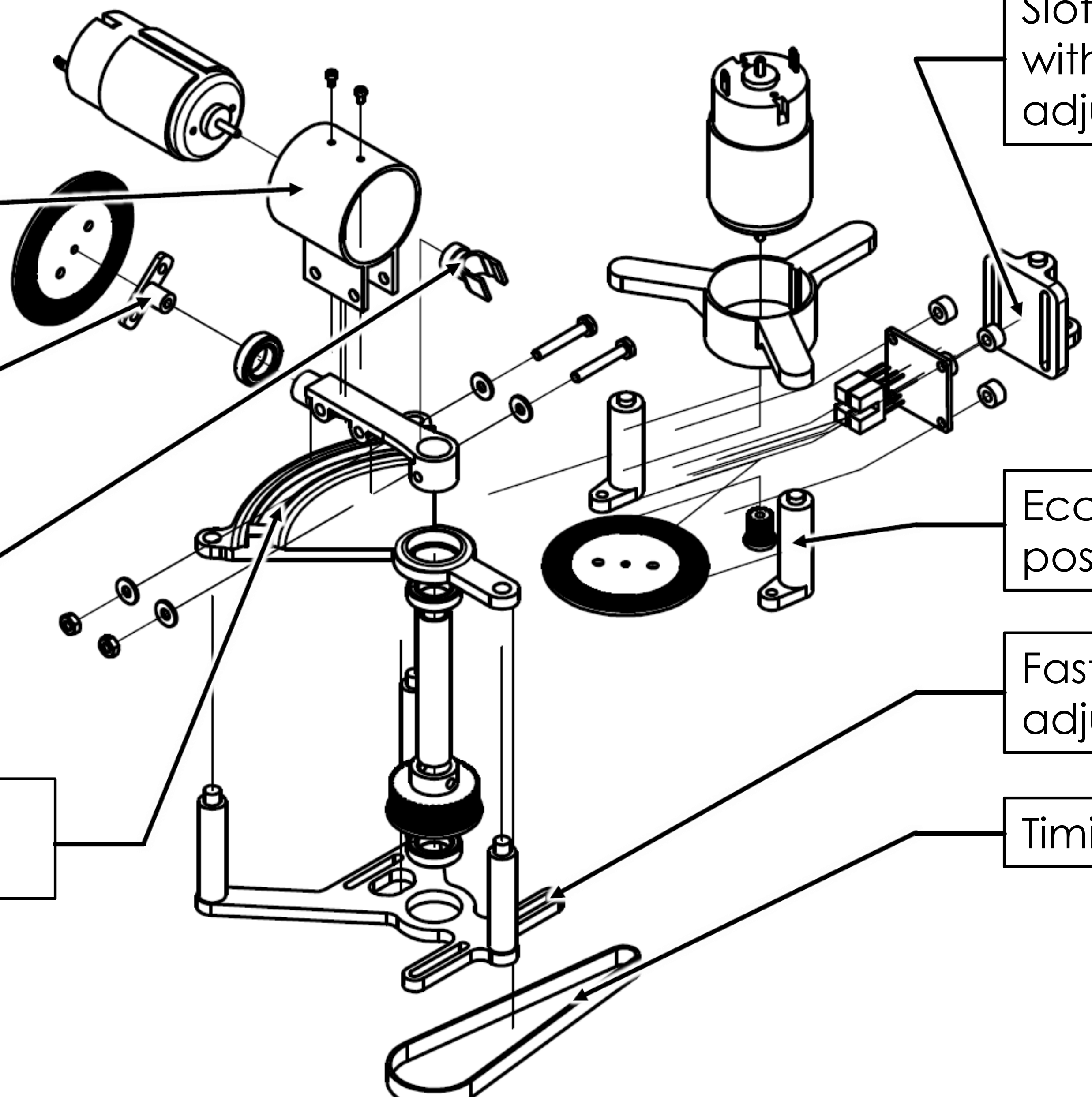


ELEC 391
Group B1
Arduino
Driver
12V
Diodes
Enc
Motor1
Motor2
Power
C1
C2



Pins from Encoder
Current Driver
Extra 5V Pins
12V Input Pins
Arduino Base
Diode Bridge
EncoderInput
C-Hdr2x4
MotorDriver
with HeatSink
Q-LN298HS
Power
DriverInput
Term-Block 2
NanoOut1
NanoIn1
NanoIn2
NanoOut2
Header 15
Motor1Out
Motor2Out
1N4148
G-Cap
100nF

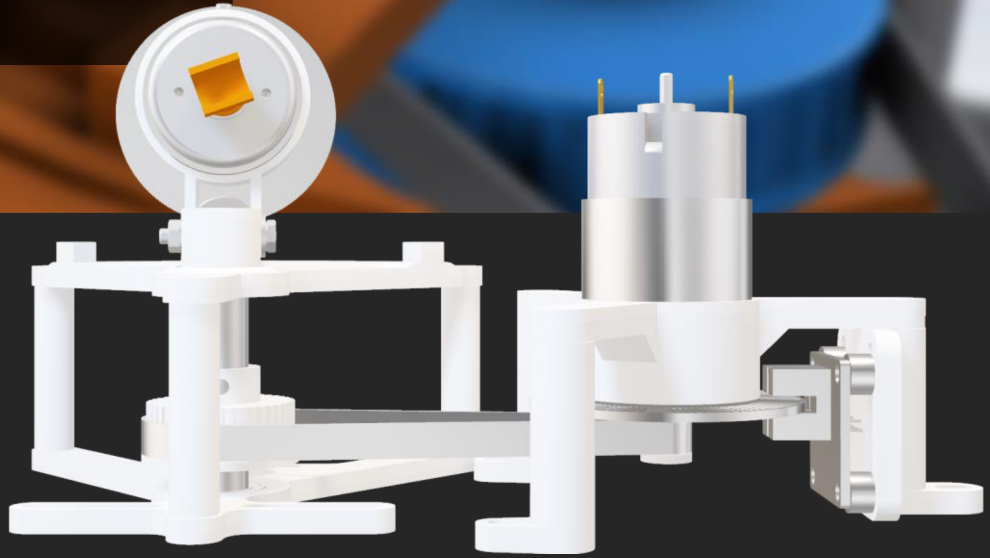
MECHANICAL FEATURES



INTEGRATION

- Integrate motors manufactured by motors sub-team
- Obtain new motor parameters
- Update system model
- Adjust mechanical design
- Retune PID controller

- Capable of 2 degree-of-freedom movements
- PID controlled yaw motor
- Fast and accurate positioning with minimum overshoot
- Accurate system model
- Modular design



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