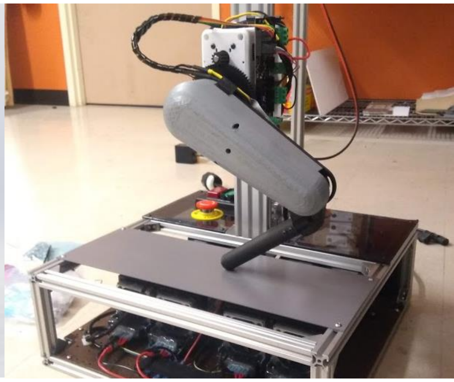
Dynamic Robotic Leg

Joseph Byrnes | Kanyon Edvall | Ahsan Qureshi

ECE 445 Senior Design: Team 1



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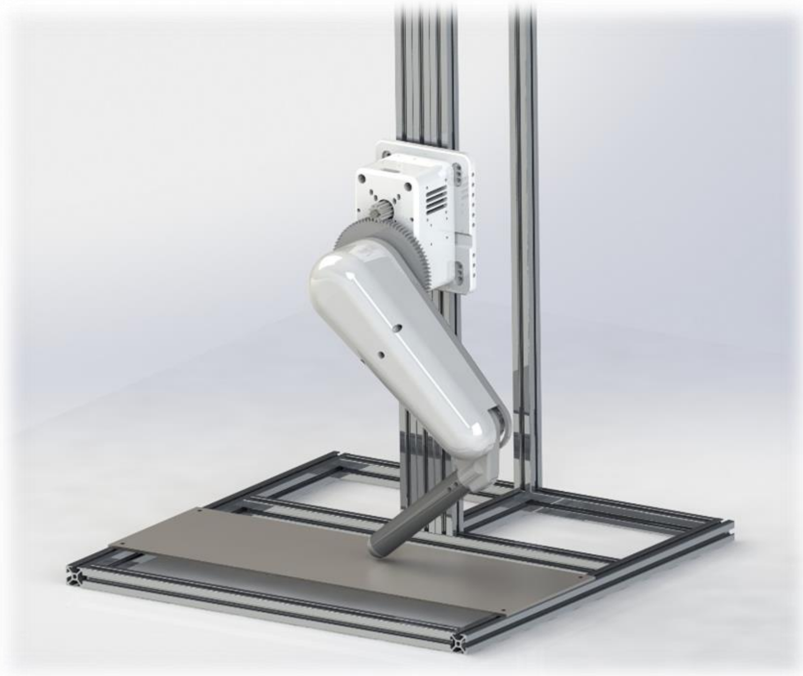
Problem Statement

- Lack of open-source, low cost legged robotics projects
  - Long development time for new research
  - High cost of development
  - High technical barrier for entry

Our Solution

- Open-Source Robotic Leg & Test Frame
  - Research and educational platform
  - Three degree of freedom system
    - Two actuated joints
  - Brushless motors
    - High torque & high efficiency
  - Comprised of 3D-printed and consumer-off-the-shelf parts



Our Solution

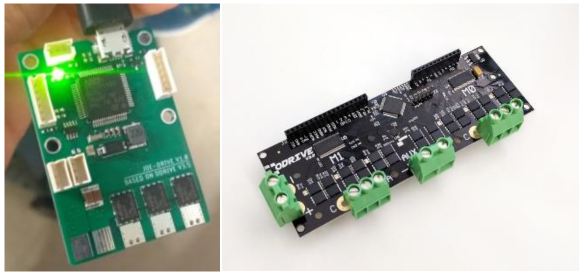
- Lowers the barrier for legged robotics algorithm development by providing an open source and functionally abstracted robotic leg

Downloadable 3D Printing Files

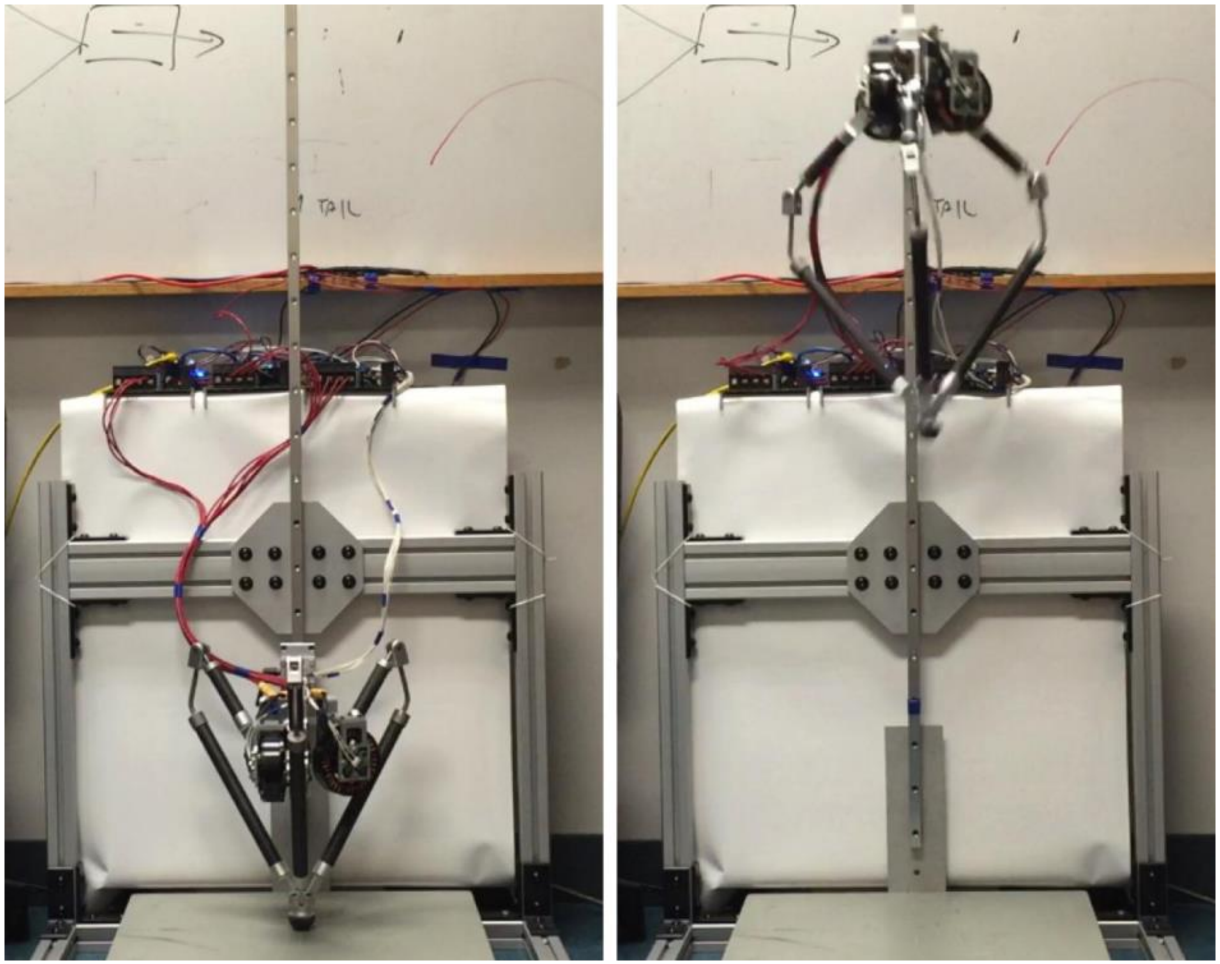
Open Source Software

```c
void implement_discrete_tf(steptraj_t *traj, float step, float *qd, float *qd_dot, float *qd_ddot) {
    int i = 0;

    traj->xk[0] = step;
    traj->yk[0] = traj->b[0]*traj->xk[0];
    for (i = 1;i<traj->size;i++) {
        traj->yk[0] = traj->yk[0] + traj->b[i]*traj->xk[i] - traj->a[i]*traj->yk[i];
    }

    for (i = (traj->size-1);i>0;i--) {
        traj->xk[i] = traj->xk[i-1];
        traj->yk[i] = traj->yk[i-1];
    }

    *qd = traj->yk[0];
    *qd_dot = (*qd - traj->qd_old)*1000;  //0.001 sample period
    *qd_ddot = (*qd_dot - traj->qddot_old)*1000;

    traj->qd_old = *qd;
    traj->qddot_old = *qd_dot;
}
```

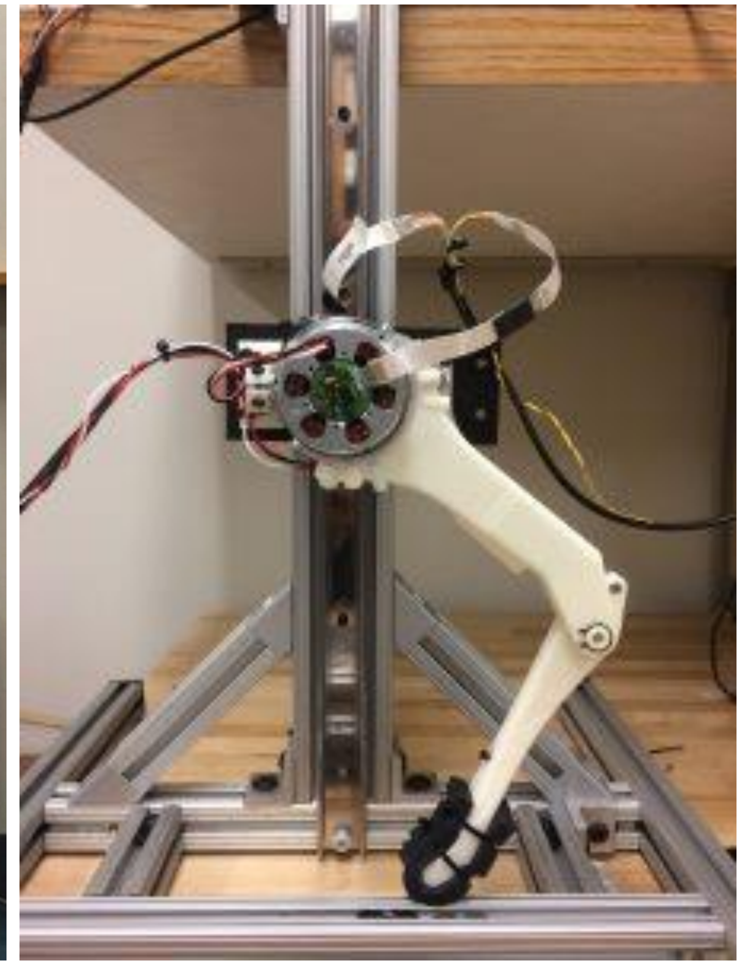
Open Source Electronics



Existing Projects and Research



https://spectrum.ieee.org/automaton/robotics/robotics-hardware/goat-robot-leg-demonstrates-explosive-jumping



https://ieeexplore.ieee.org/document/8202172

Project Highlights

- Low Cost
- Fully Open-Source
- High Torque Density
- Simple 2 Degree of Freedom actuation

Simulation in MATLAB

- Code Shared on GitHub

- Includes a Simulink Block Breakdown of Entire System

- User can edit as needed, adding parts or changing controller as desired

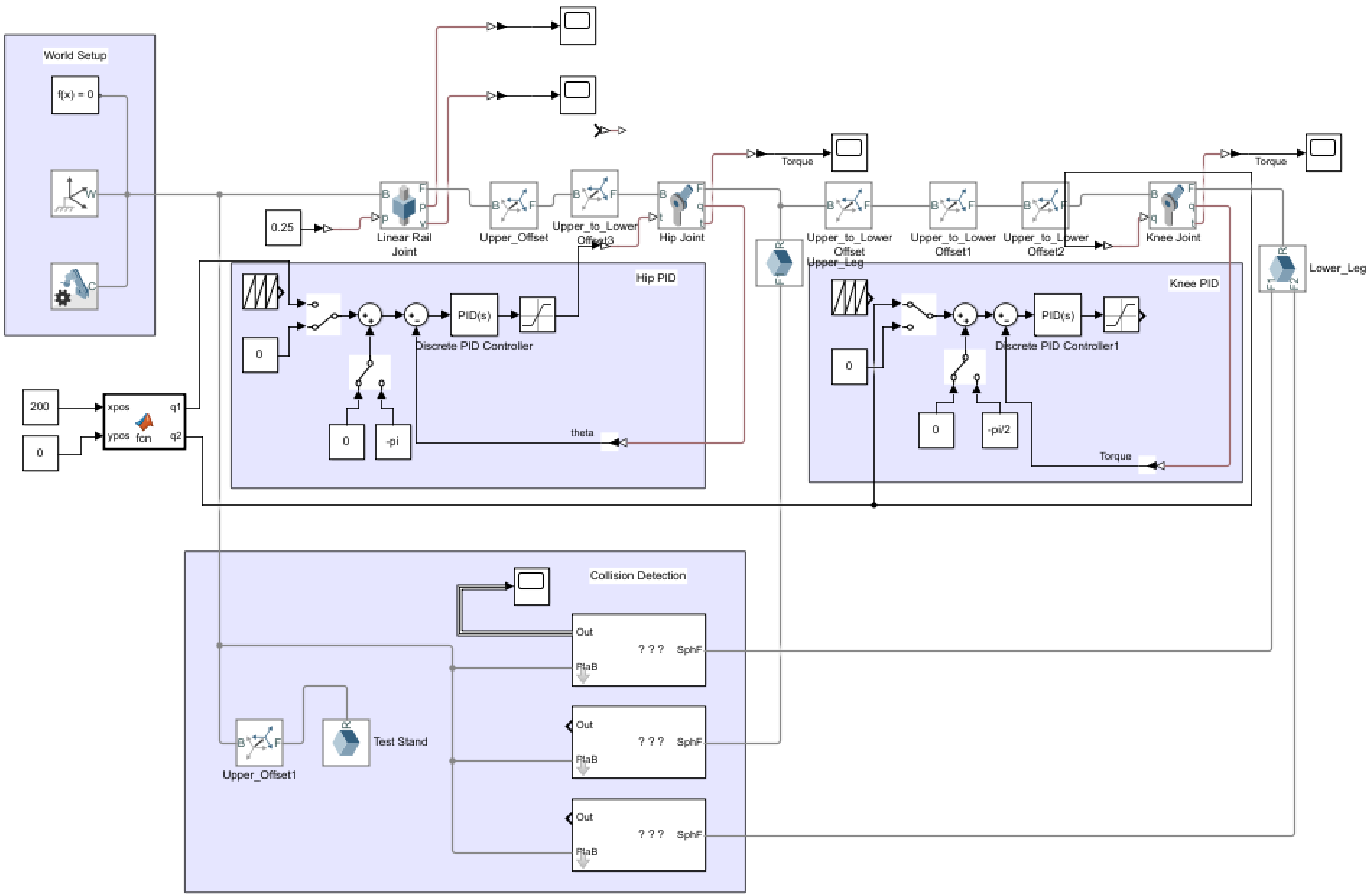
Inverse Kinematics

$$q2 = -cos^{-1}(\frac{x^2 + y^2 - a_1^2 - a_2^2}{2 * a_1 * a_2})$$

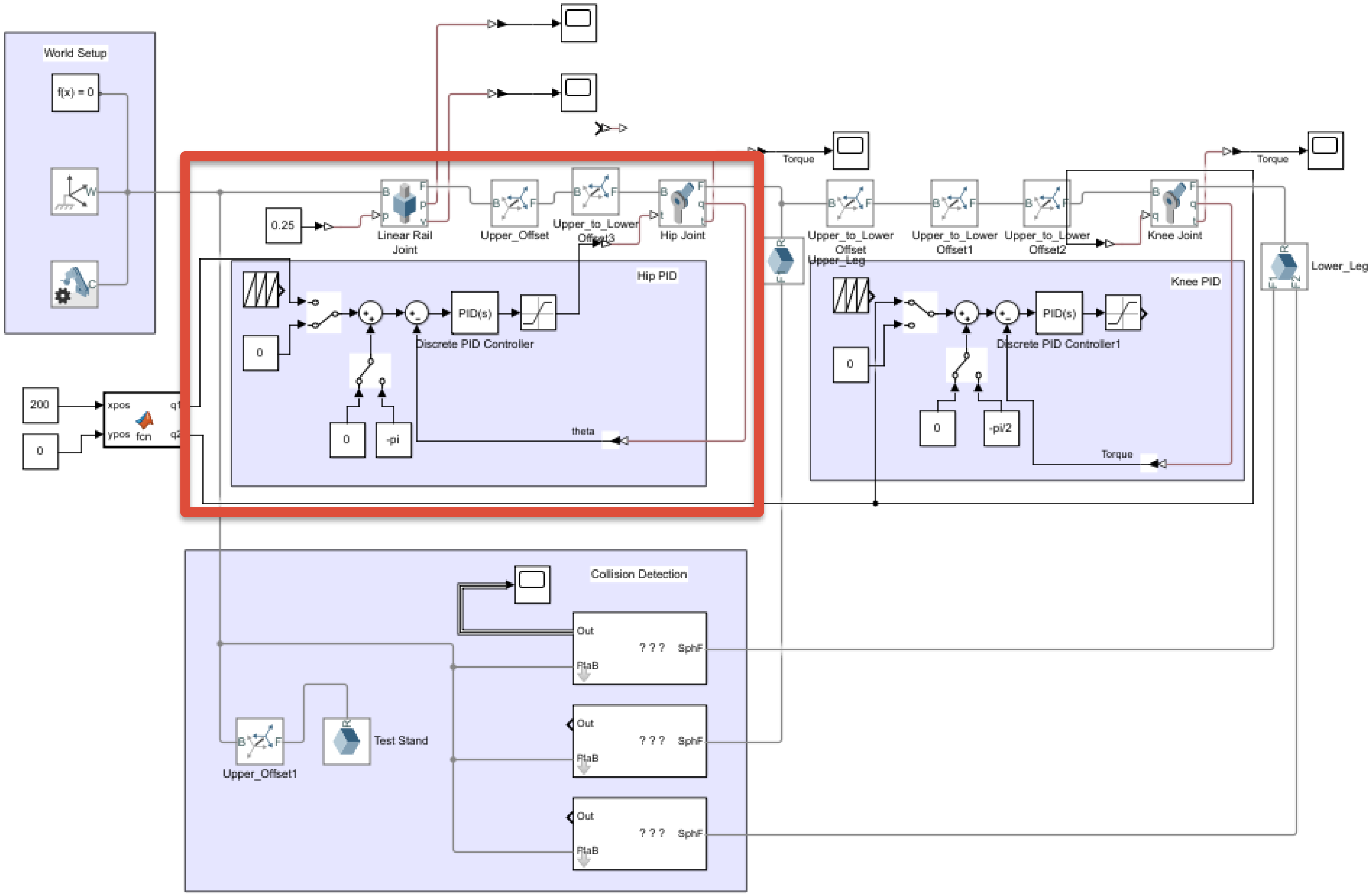
$$q_1 = atan2(y, x) + atan2(a_2 * sin(q_2), a_1 + a_2 cos(q_2)) - q_2$$

q_1	Hip Motor Angle
q_2	Knee Motor Angle
a_1	Upper Leg Link Length
a_2	Lower Leg Link Length
x	Horizontal Position Set Point
y	Vertical Position Set Point

Simulink Block Diagram



Simulink Block Diagram



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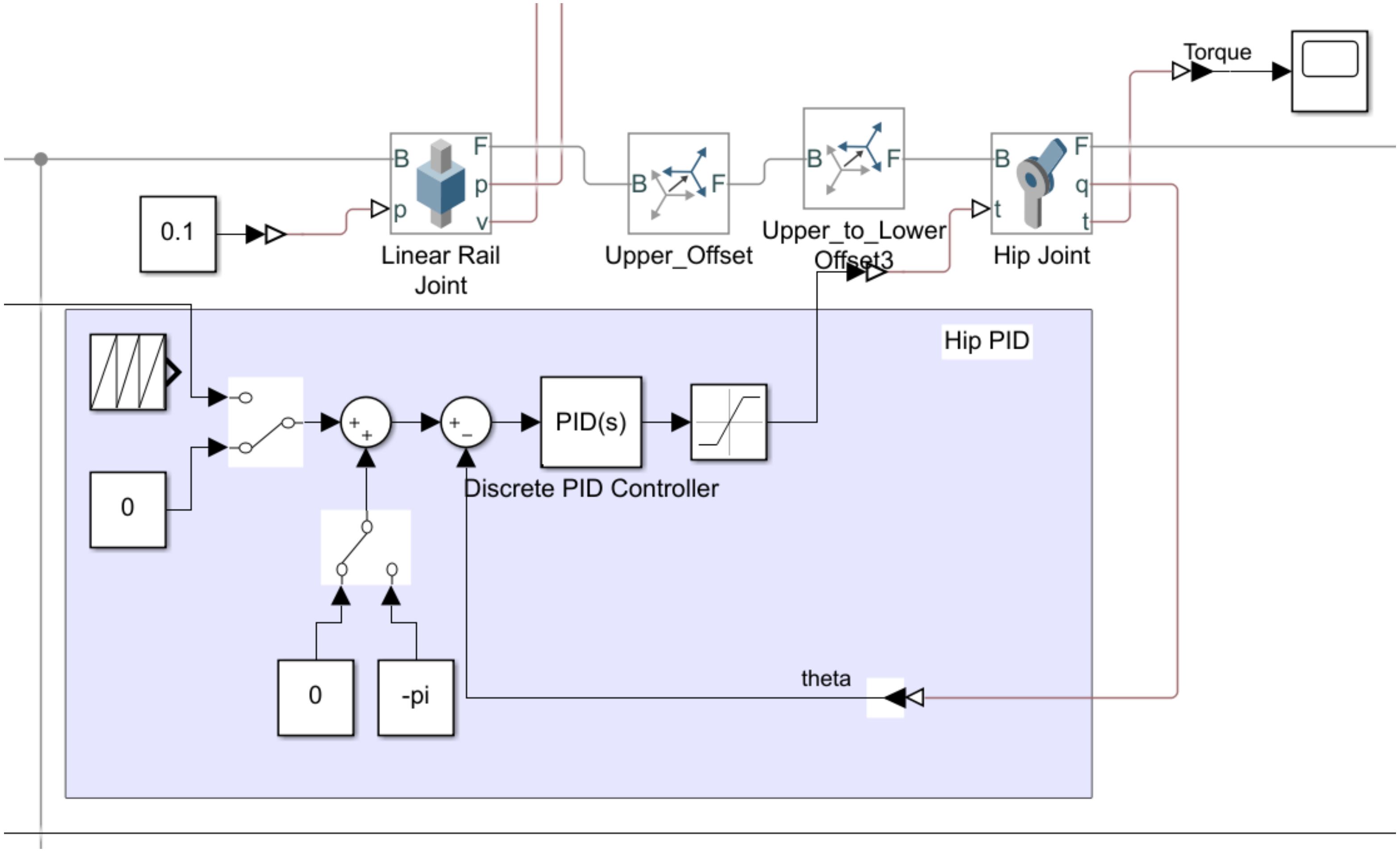
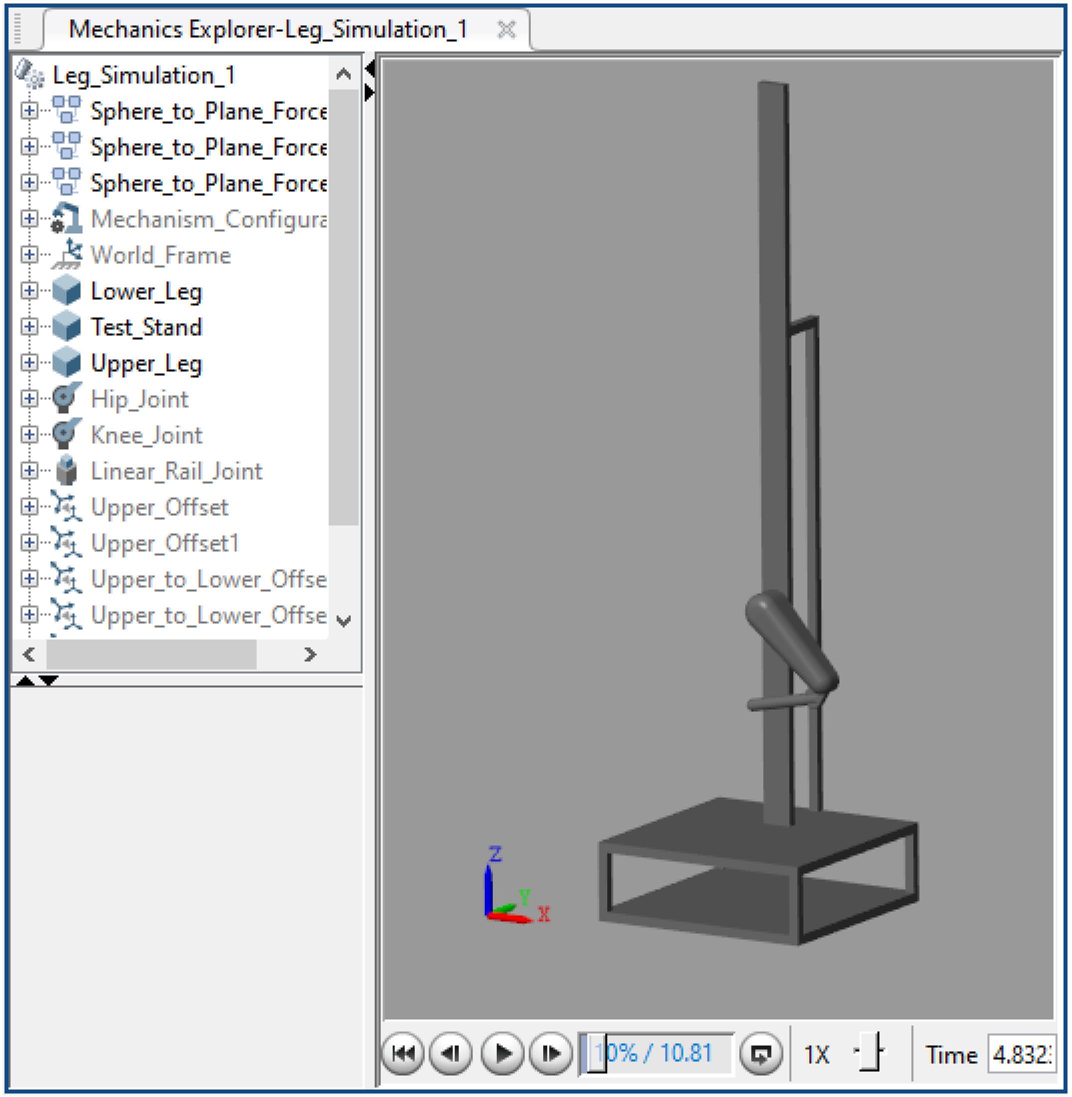
Hip Joint Controller



SimScape Multi-Body Simulation



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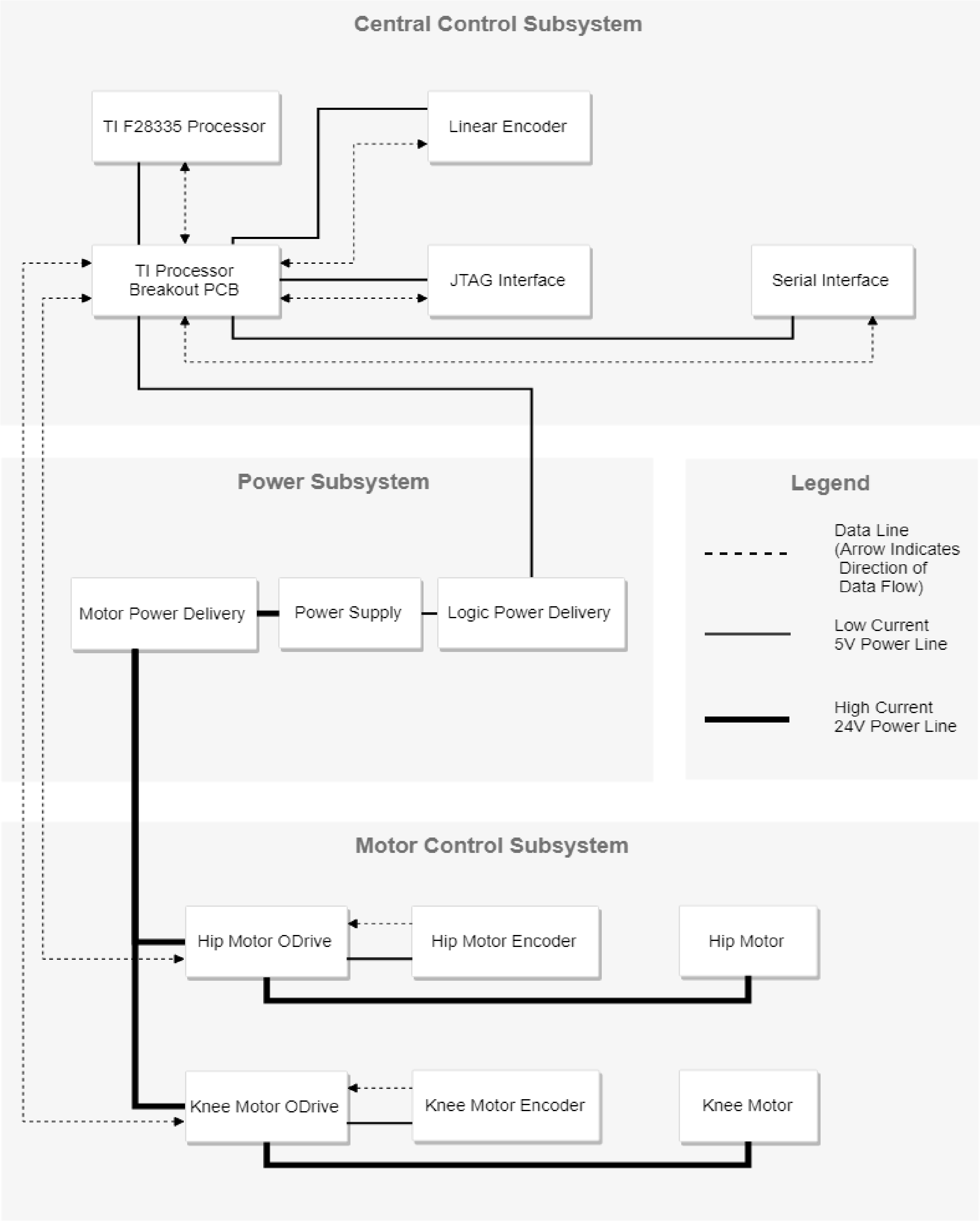
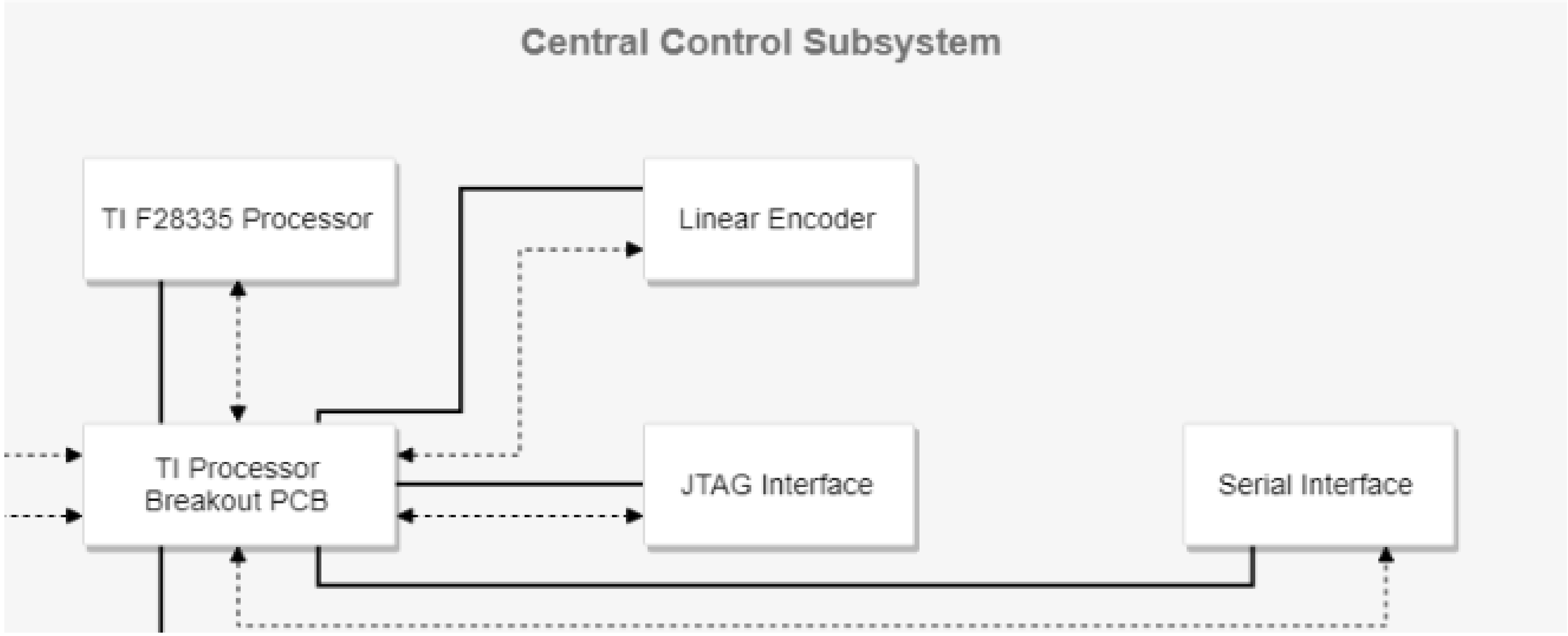
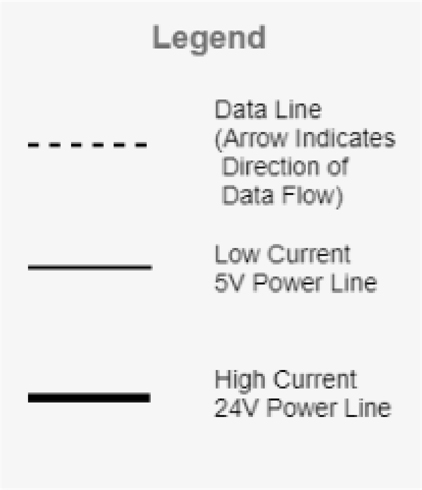
Design

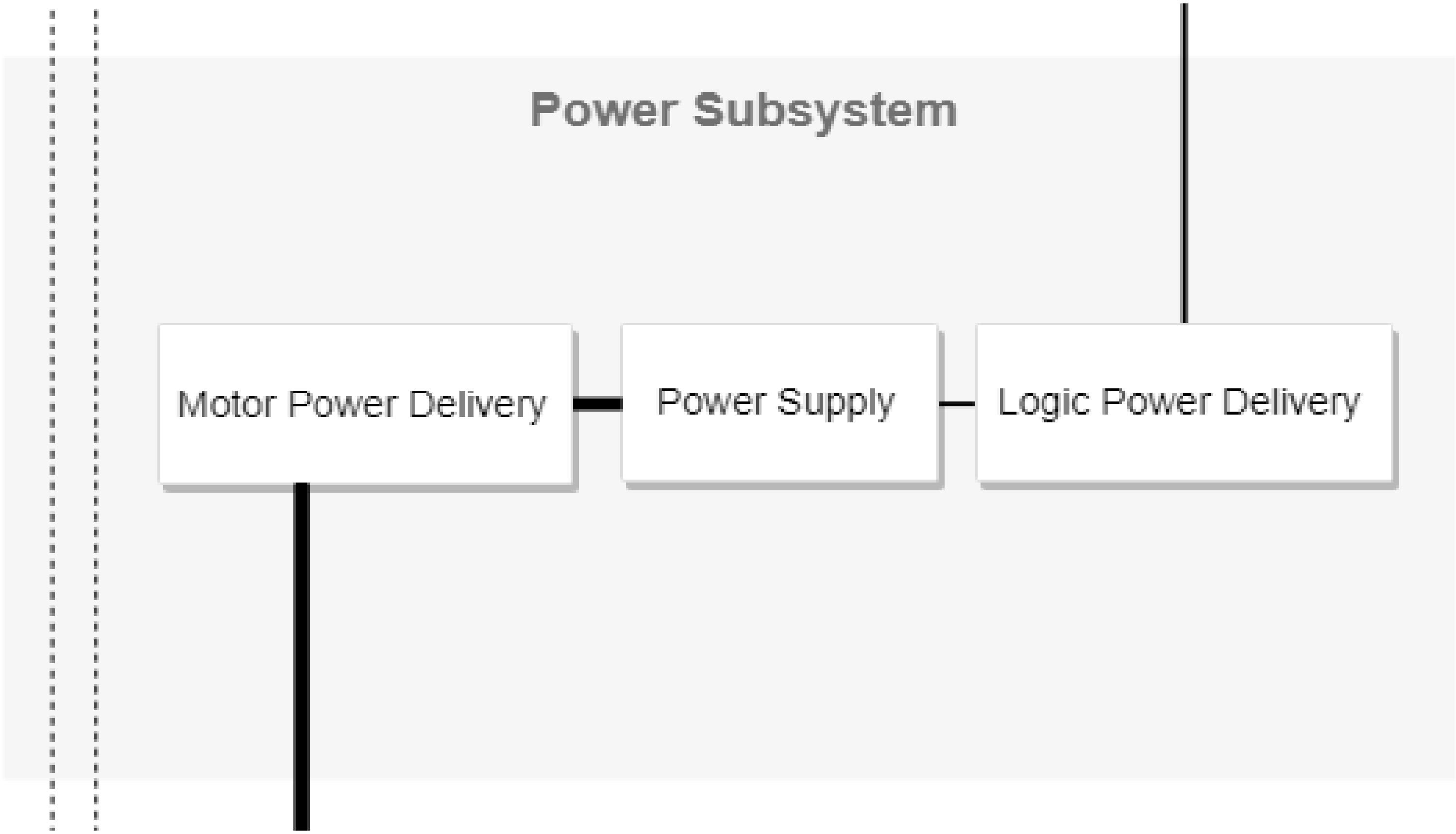
- Subsystems
  - Control Logic & Sensing
  - Motor Control
  - Power Delivery





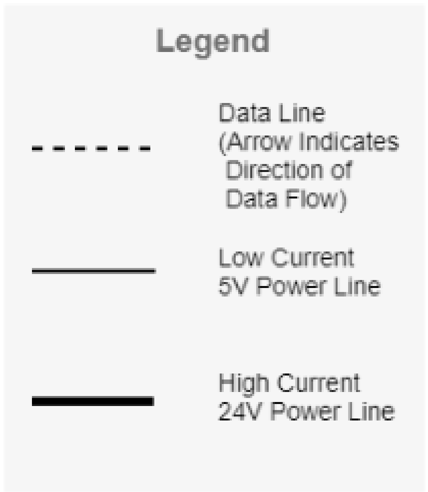
- Control Logic & Sensing
  - Texas Instruments F28335 DSP
  - Python scripts for control over USB
- Communication
  - Serial Interface
  - JTAG Debugging Port

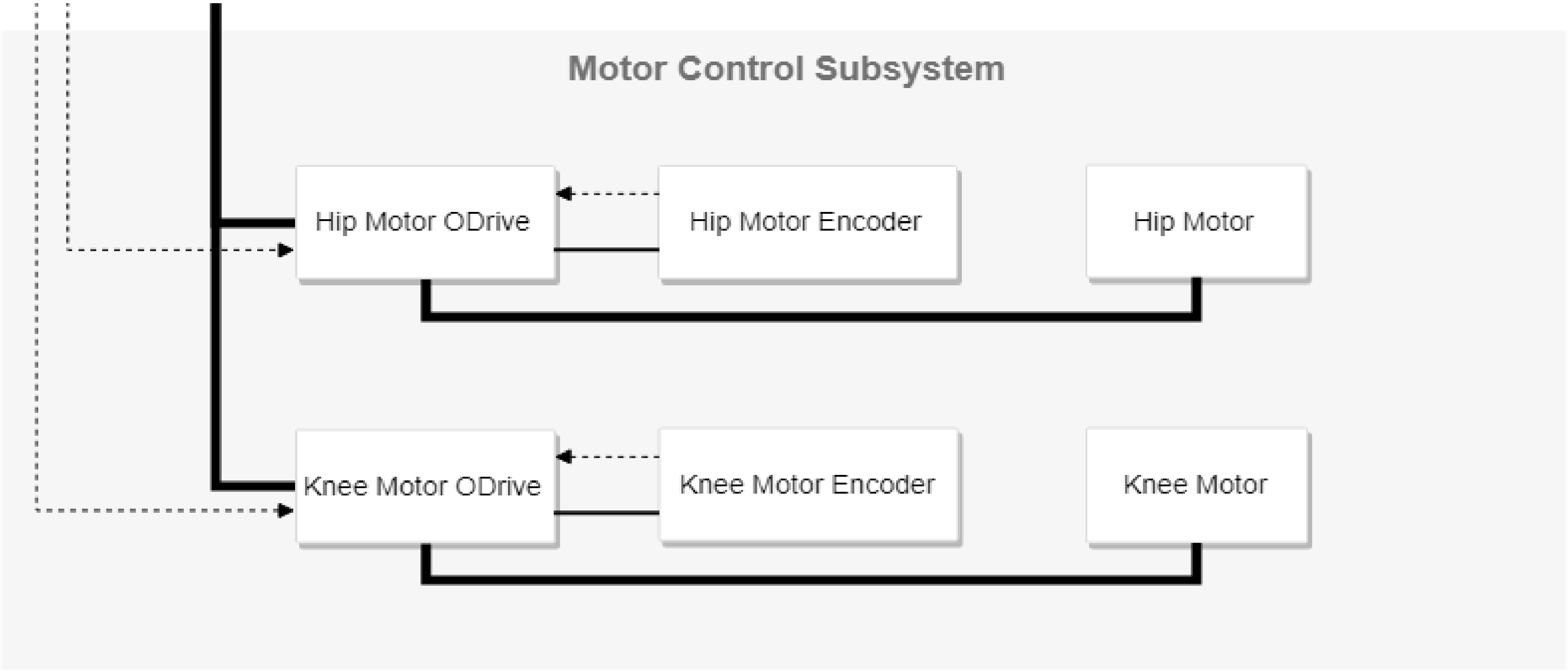




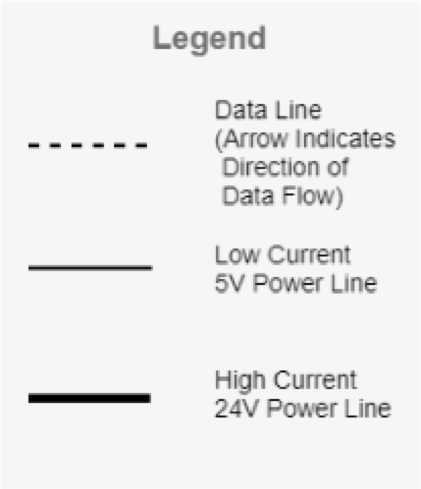
- Motor Power Delivery
  - Two 750w 12v Power Supplies
  - 60A Circuit Breaker

- Logic Power Delivery
  - 24v to 5v Switching Regulator



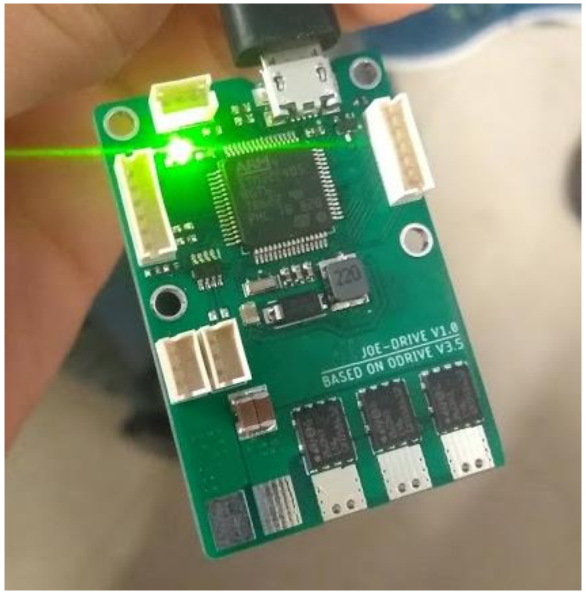


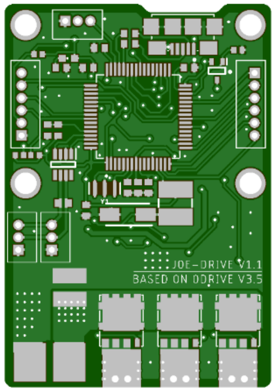
- Motor Control
  - 0.16 Nm/A BLDC Motors
  - 2000 CPR Magnetic Encoders
  - ODrive Motor Controller

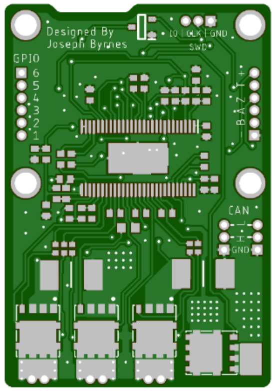


JoeDrive - Overview

- Motor Controller Based on ODrive v3.5
- Controls Torque, position, and velocity of single BLDC Motor
- 2-layer PCB
- 46 mm tall, 32 mm wide
- Costs under $30 to produce



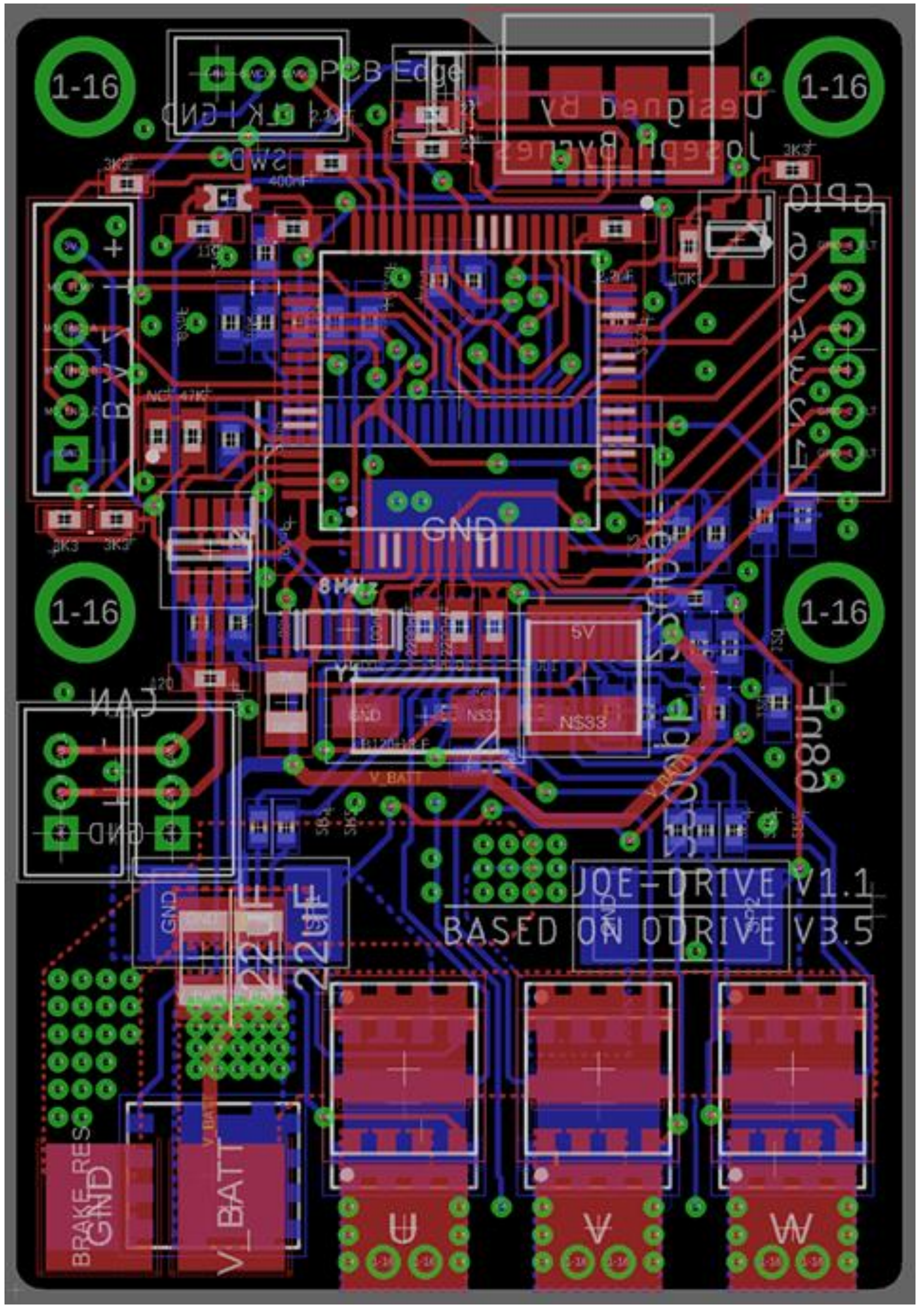




JoeDrive - Layout

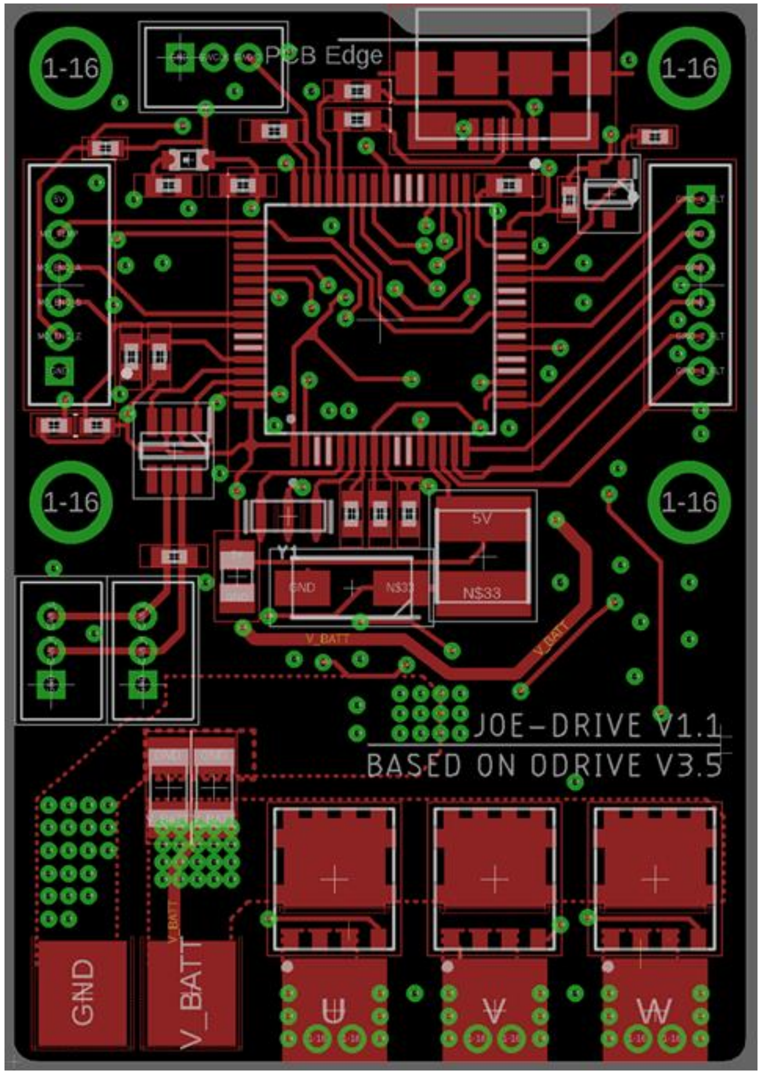
– Far more compact than the standard ODrive

– Connections:
  - Encoder/Hall Sensors
  - Two CAN Ports
  - Programming and GPIO
  - USB

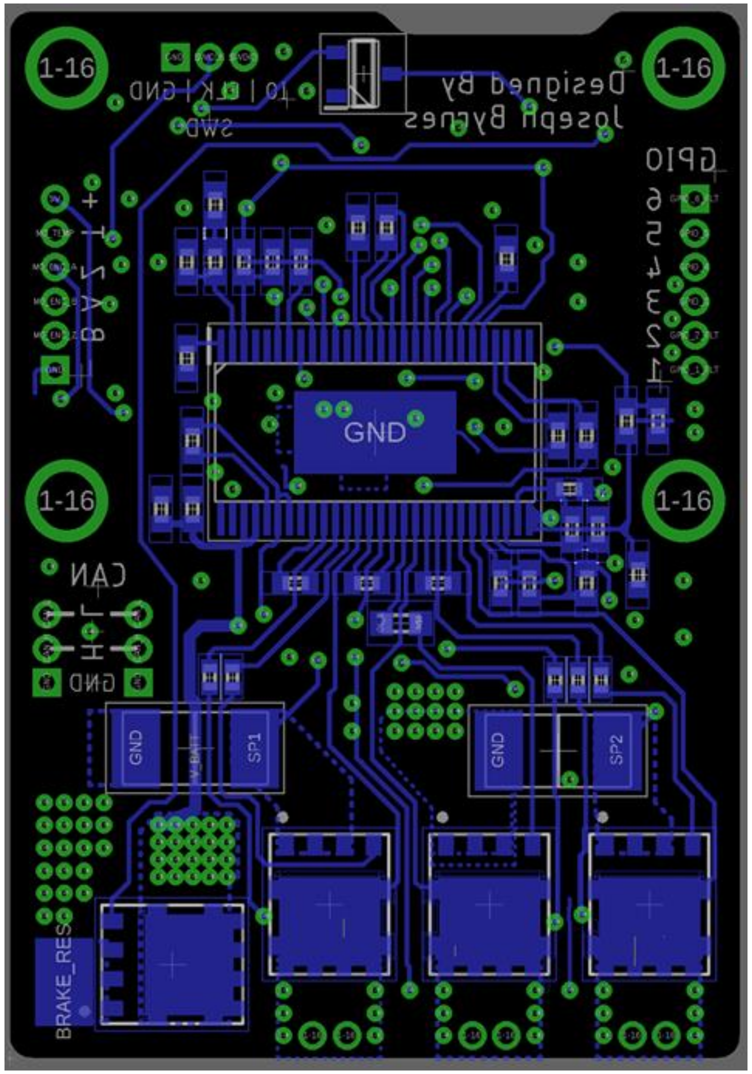


Logic Circuit

Power Circuit



Top



Bottom

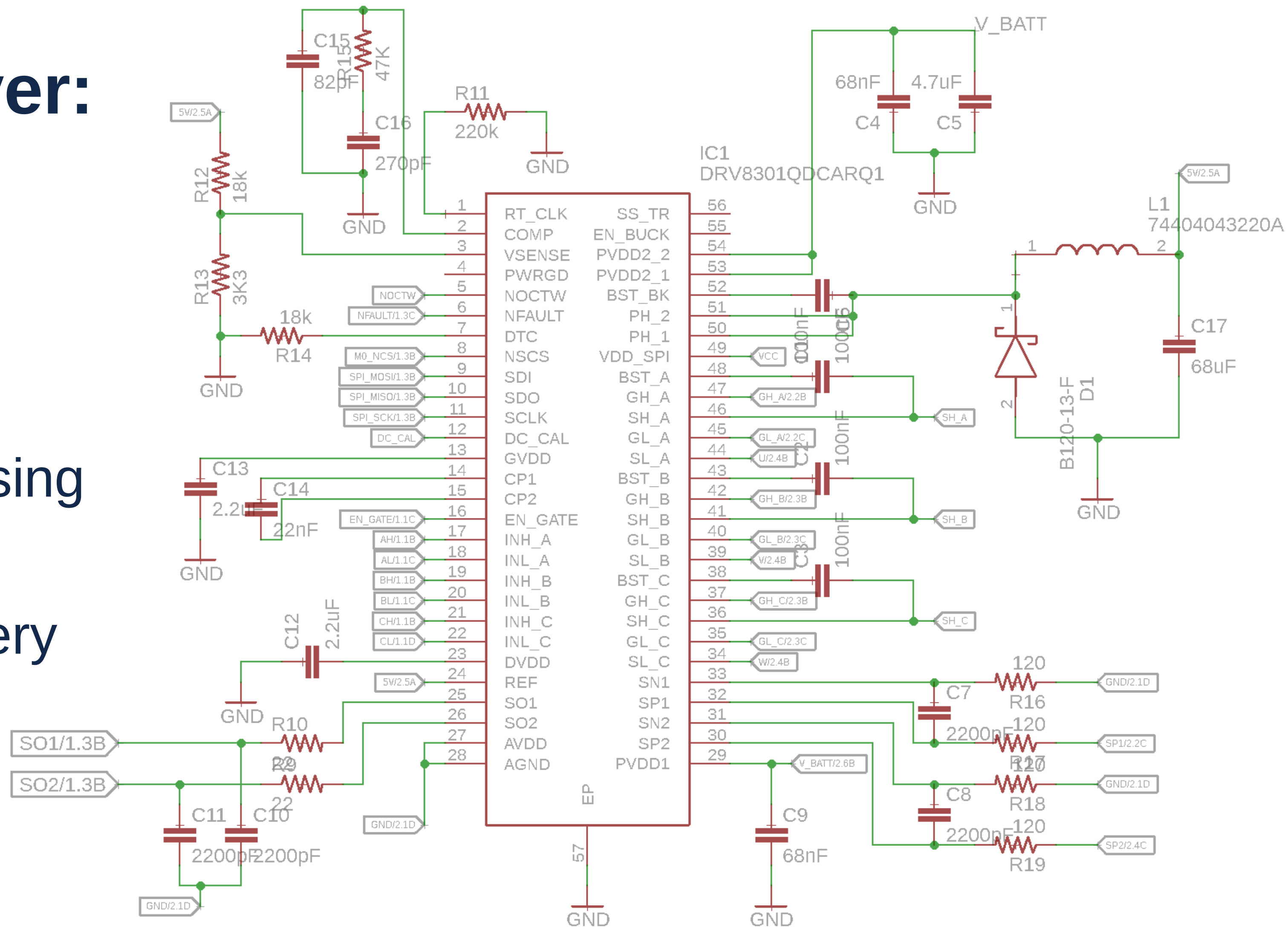
JoeDrive - Schematic

Gate Driver:

Based on ODrive v3.5

Current Sensing

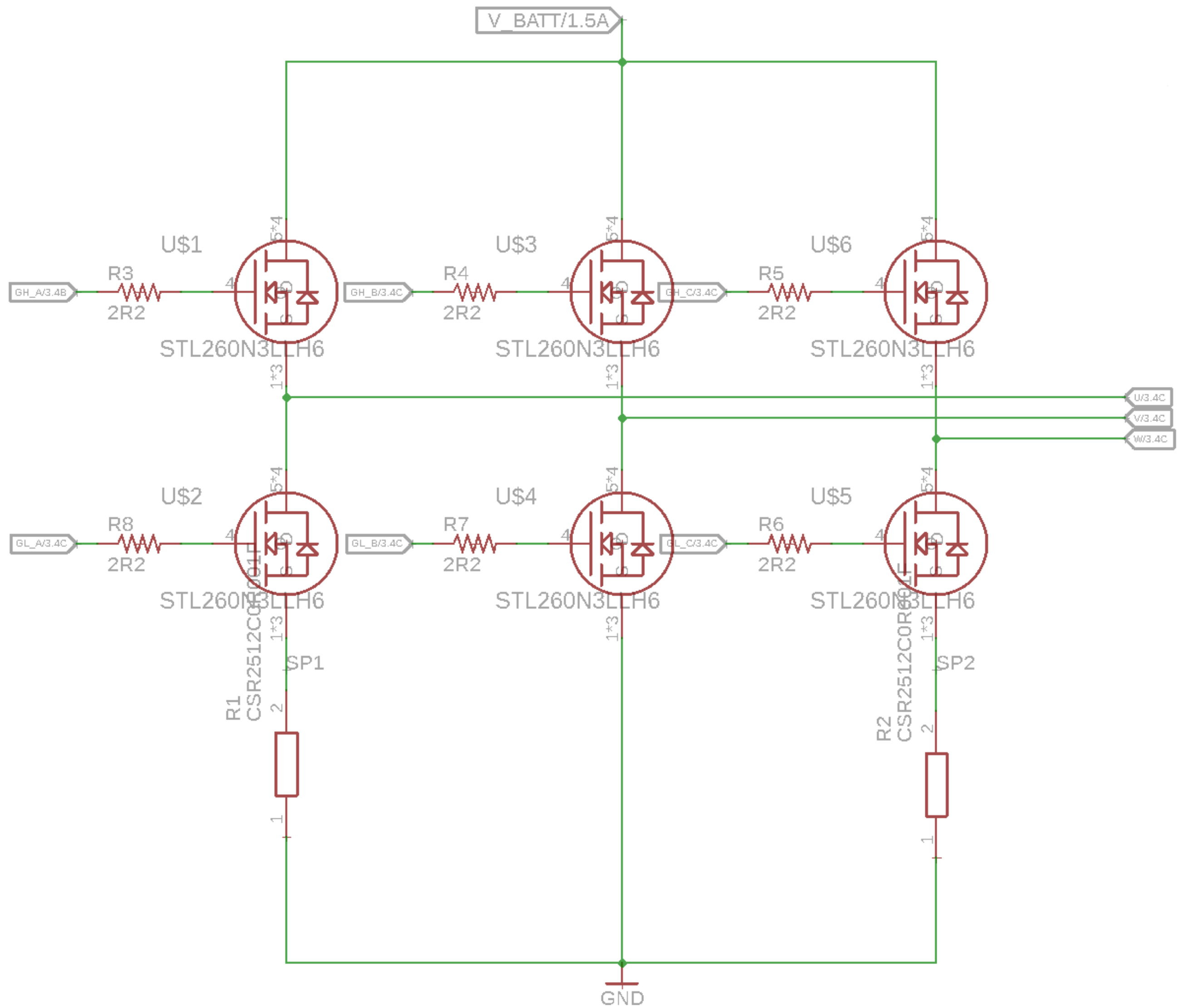
Power Delivery for STM32



JoeDrive - Schematic

Power Stage:

- 45 A continuous current MOSFETs
- Two Shunt resistors for FOC and Current Control



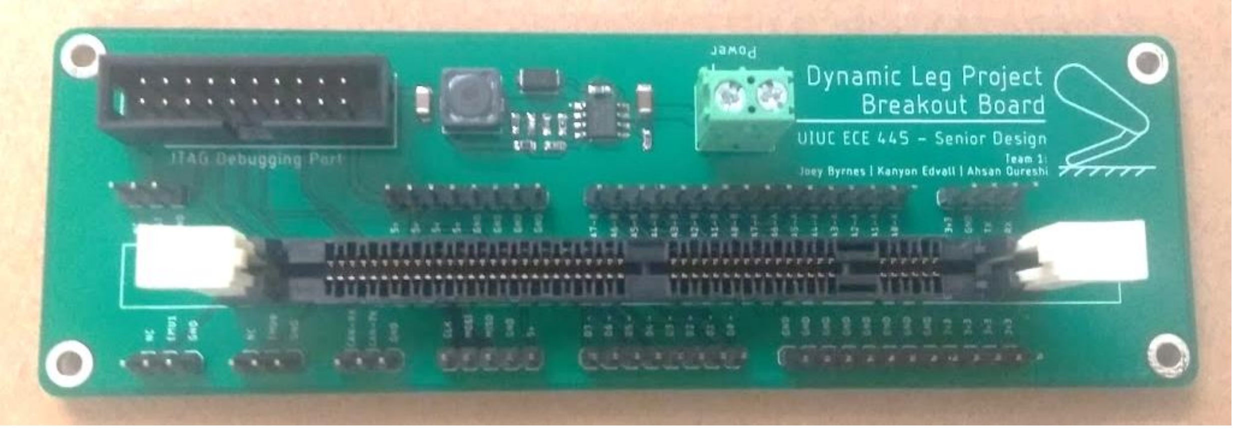
JoeDrive - Hardware

- Hardware Issues
  - Brake resistor MOSFET
  - DRV 3.3V output
  - Current Sensing resistors
  - Analog VCC shorted to GND

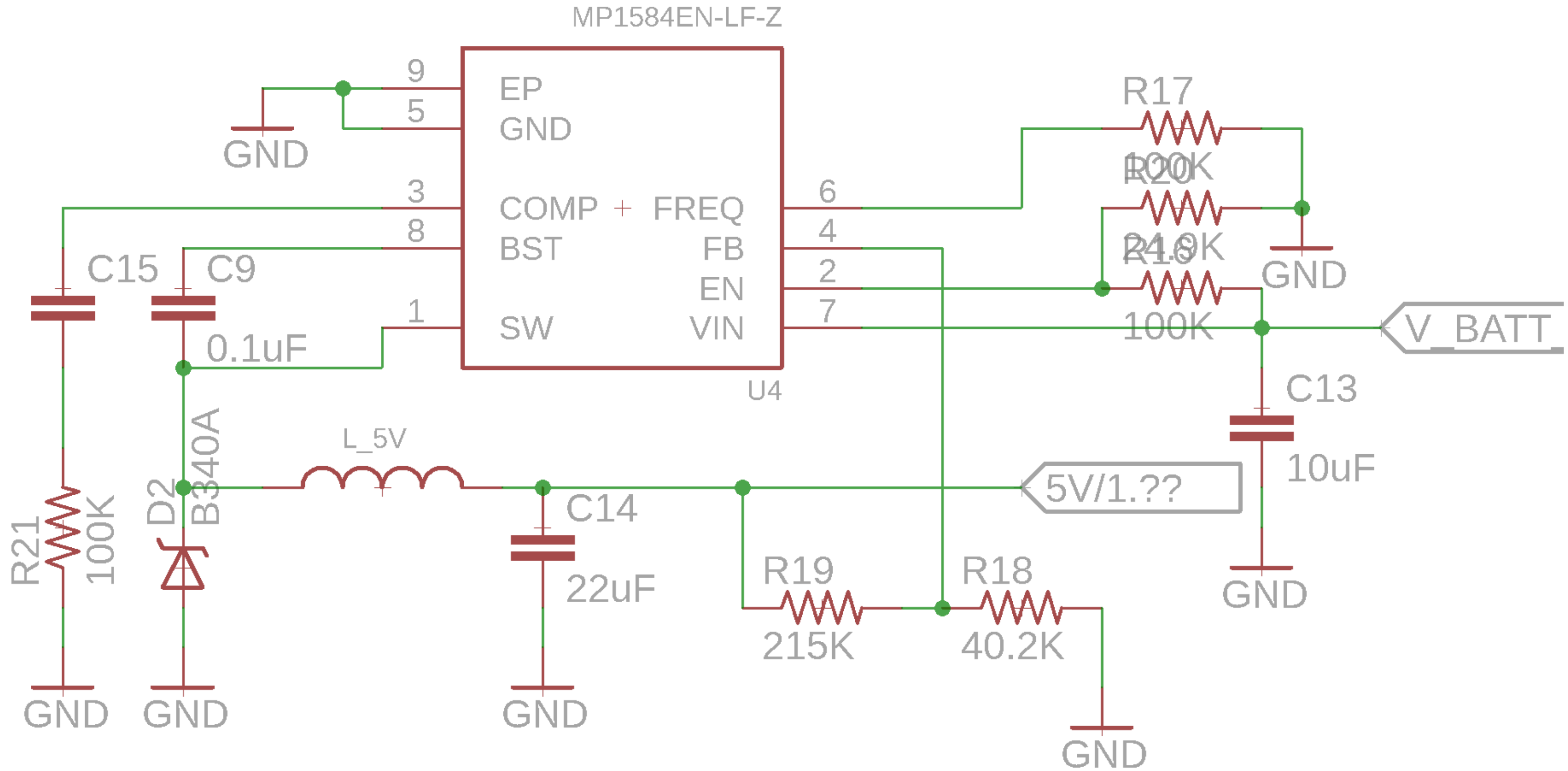
- Hardware problems fixed in JoeDrive v1.1

F28335 DSP Breakout Board

- Provides conversion from TI 14 pin JTAG to SEGGER 20 pin JTAG debugger port
- Provides connections to necessary GPIO
- Regulates power supply voltage down to 4.9 V to 5.5 V using switching regulator



F28335 DSP Breakout Board



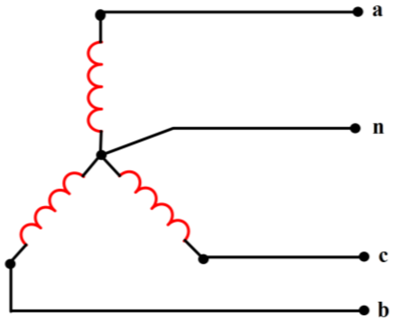
24 V to 5 V Switching Regulator

BLDC Motors

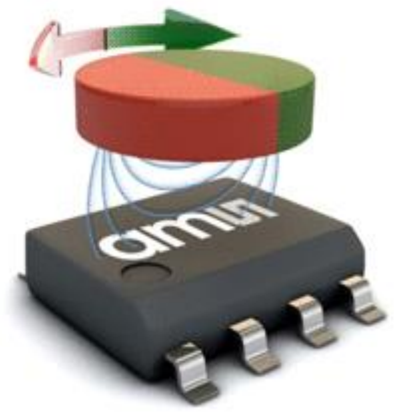
– Choosing motors with sufficient torque and power rating was vital to the success of our project

– Important Specifications

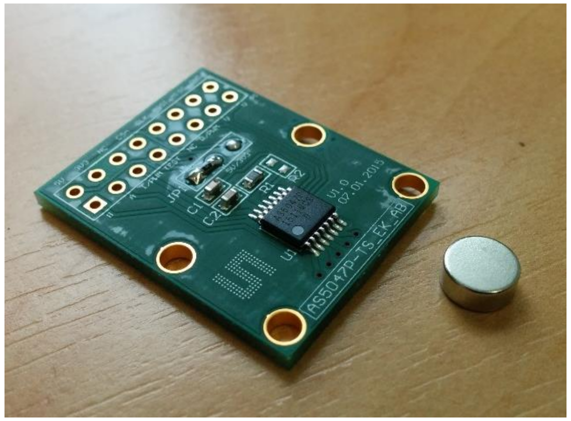
- 0.16 Nm/A Torque constant
- 2450 watt power rating
- Diameter of 63 mm, Length of 55 mm
- 3 mm Keyed output shaft
- WYE coil termination
- 558 grams



Magnetic Encoders



- AS5047D Magnetic encoders
  - small form factor
  - low price
  - Allow for both quadrature and absolute outputs
  - Simple installation
  - 2000 counts per revolution

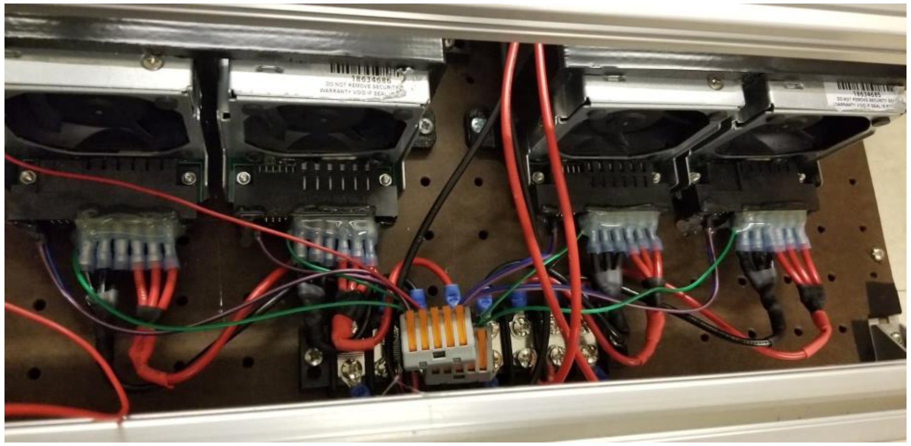


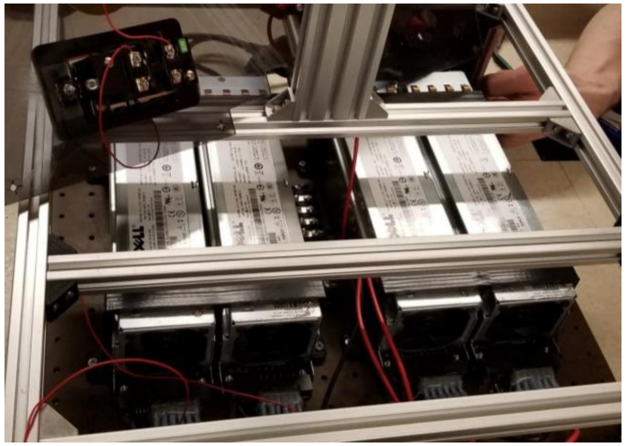
Development Stand

- Compatible with multiple wall outlet types
- 5 types of safety features including multiple E-Stops, circuit breaker, and switches

Development Stand

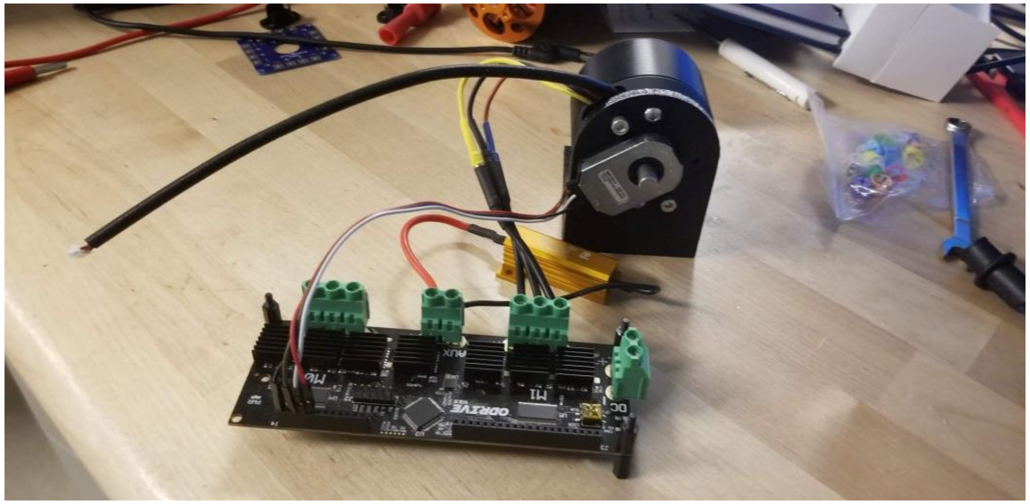
- Power Supplies
  - Two 12V supplies in series. Produces 1500W at 24V.
  - Two PSUs modified for floating ground. Allows boosting to 24V
  - Relays control power supply output





Motor Control

- PID Tuning
  - Position control tracks angle setpoint
  - PID tuned for strong disturbance rejection and minimal vibration
  - Allows for accurate position tracking



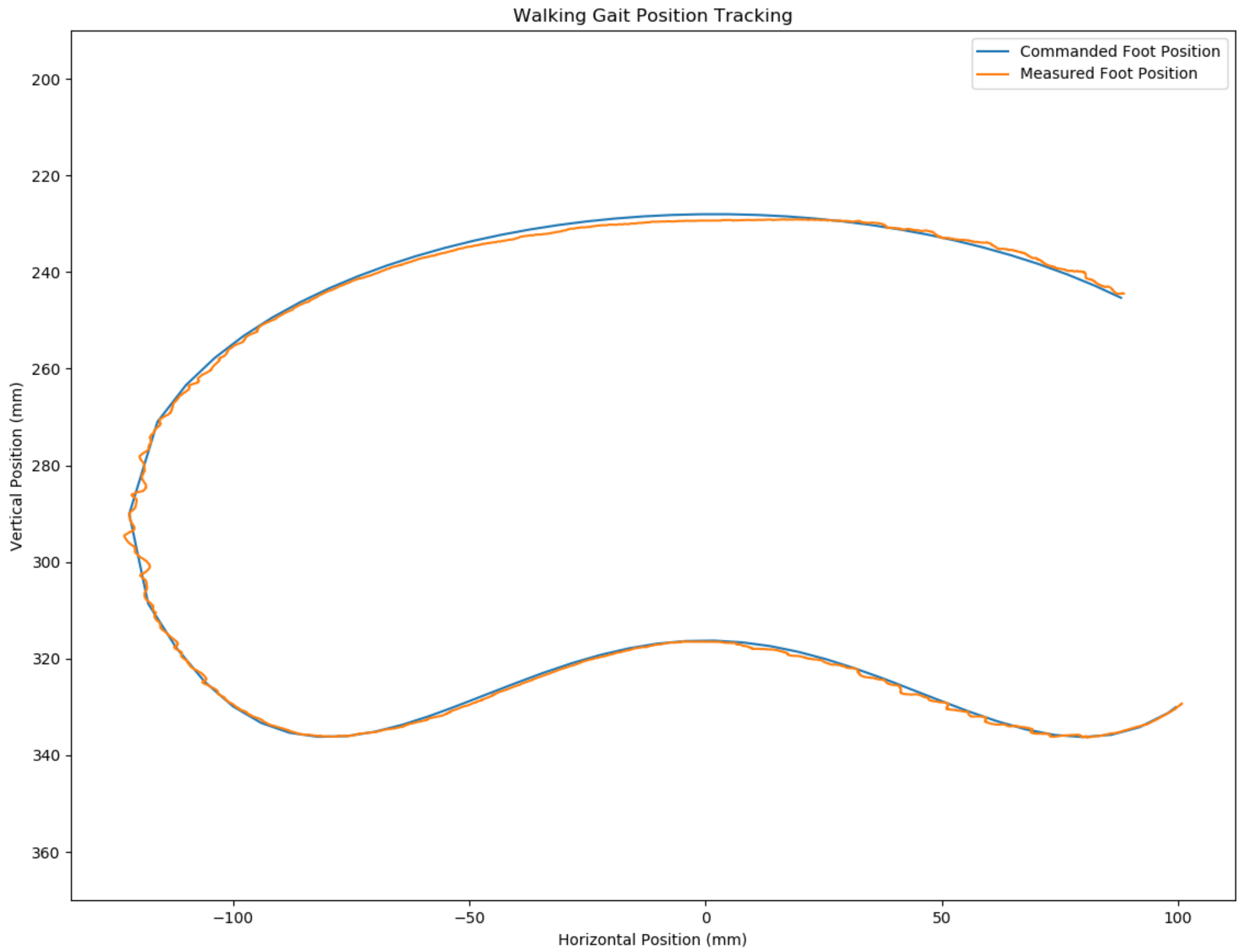
ODrive Interface

- Python Interface for ODrive
  - Allows for trajectory tracking of predefined paths
  - Uses an inverse kinematics controller
  - Plots current / position of motors
  - Variety of control options

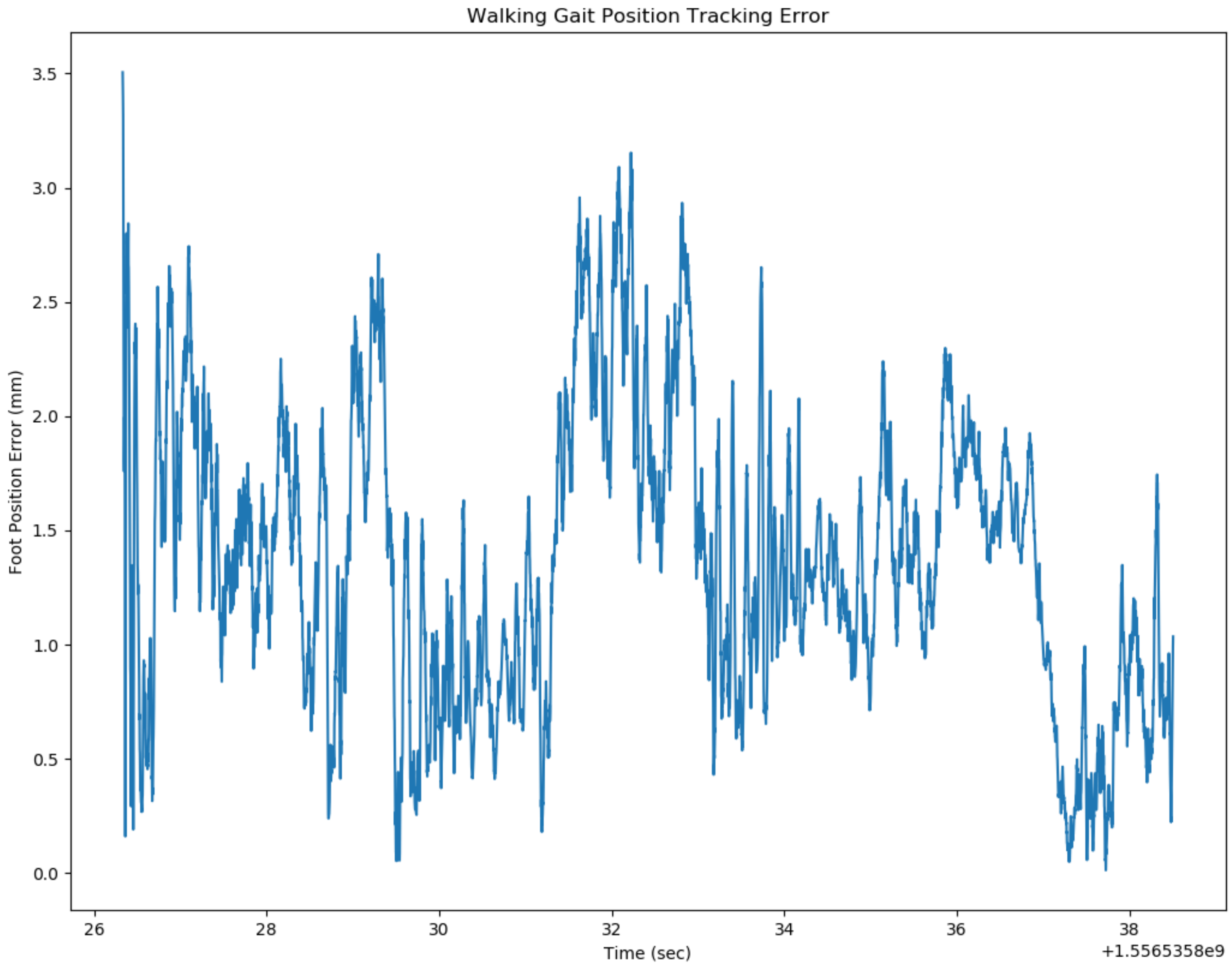
Command Prompt - py Leg_Demo.py

```
Init done
Welcome to the Dynamic Robotic Leg Motor Control Interface


Enter X: 0
Enter Y: 200
Using X: 0.0, Y: 200.0
Generated q2: -1.9635307131572455, q1: 2.5525616833735194
Knee setpoint: -3906.320236396626
Hip setpoint: -2404.588362598667
Continue? Y / N: y


Enter X: 0
Enter Y: 360
Using X: 0.0, Y: 360.0
Generated q2: -0.0, q1: 1.5707963267948966
Knee setpoint: 0.0
Hip setpoint: -18.18181818181847
Continue? Y / N: Y


Enter X:
```

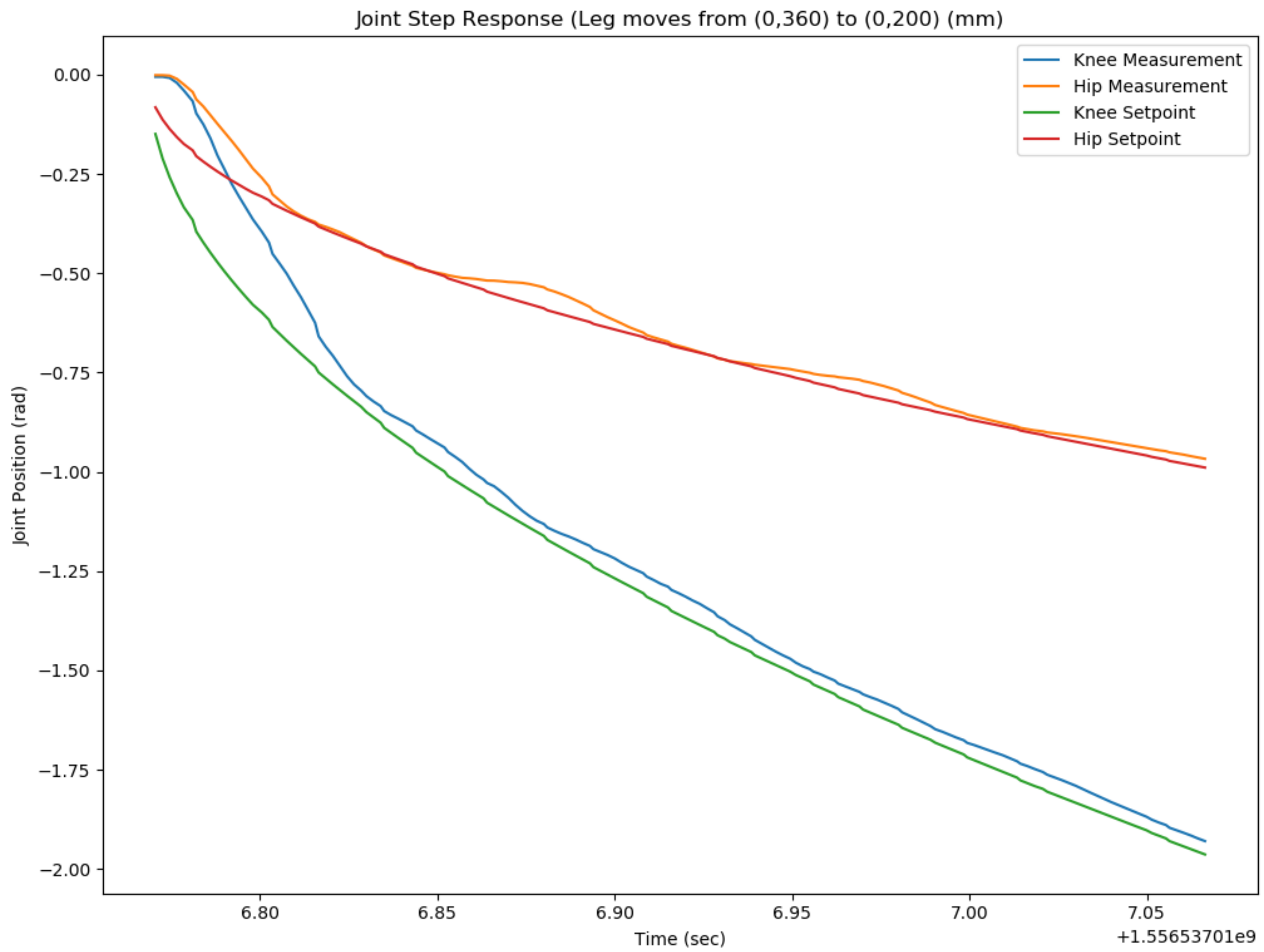
Trajectory Tracking



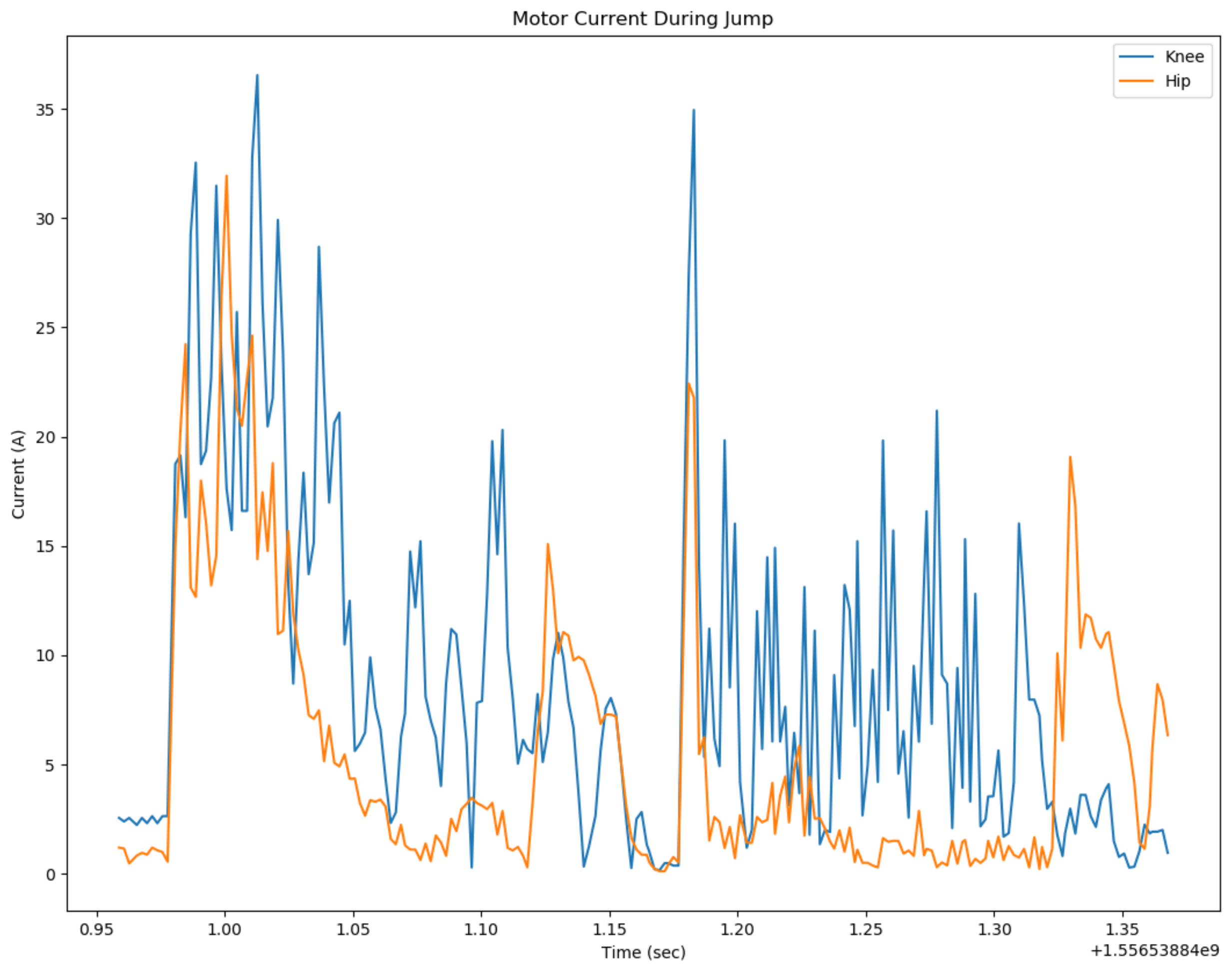
Tracking Error During Walking Gait

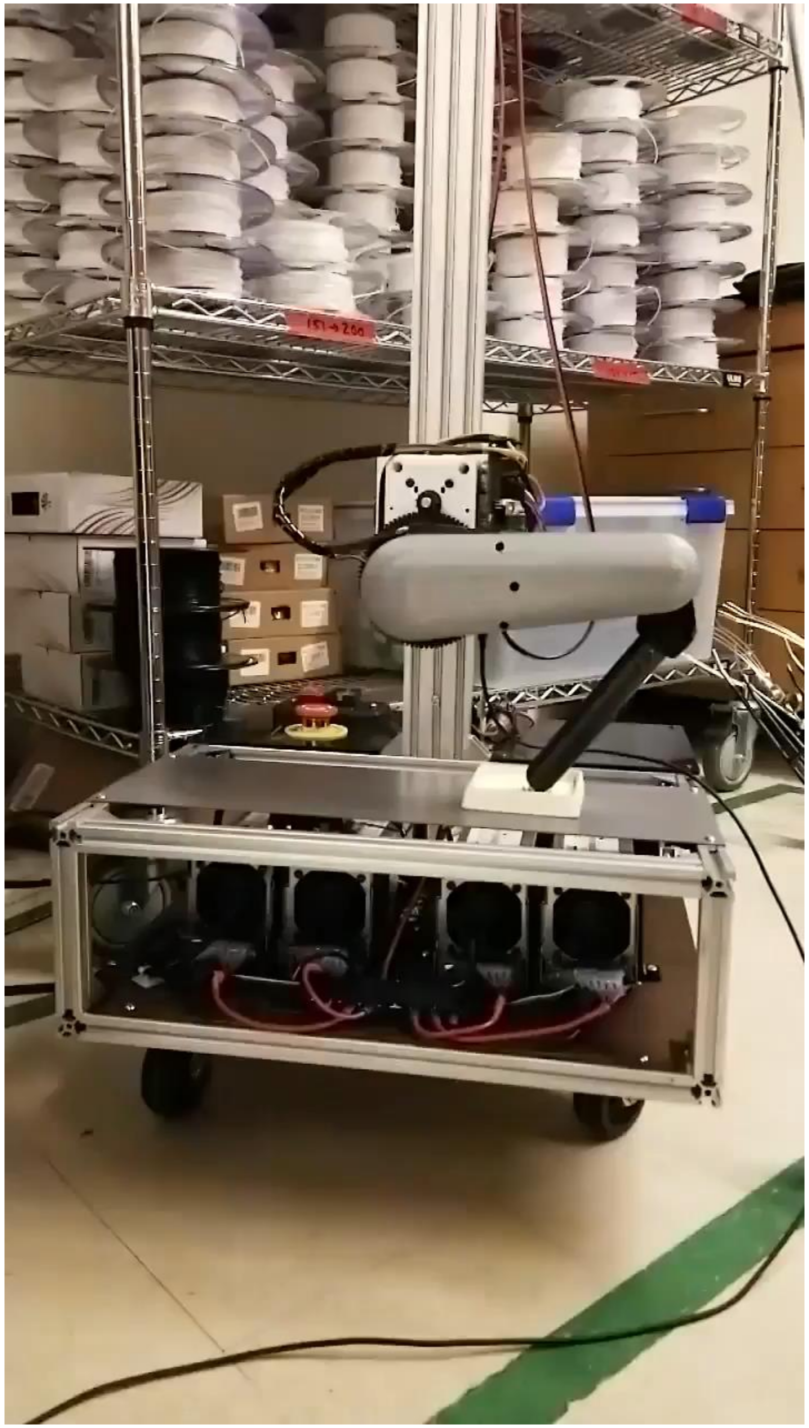


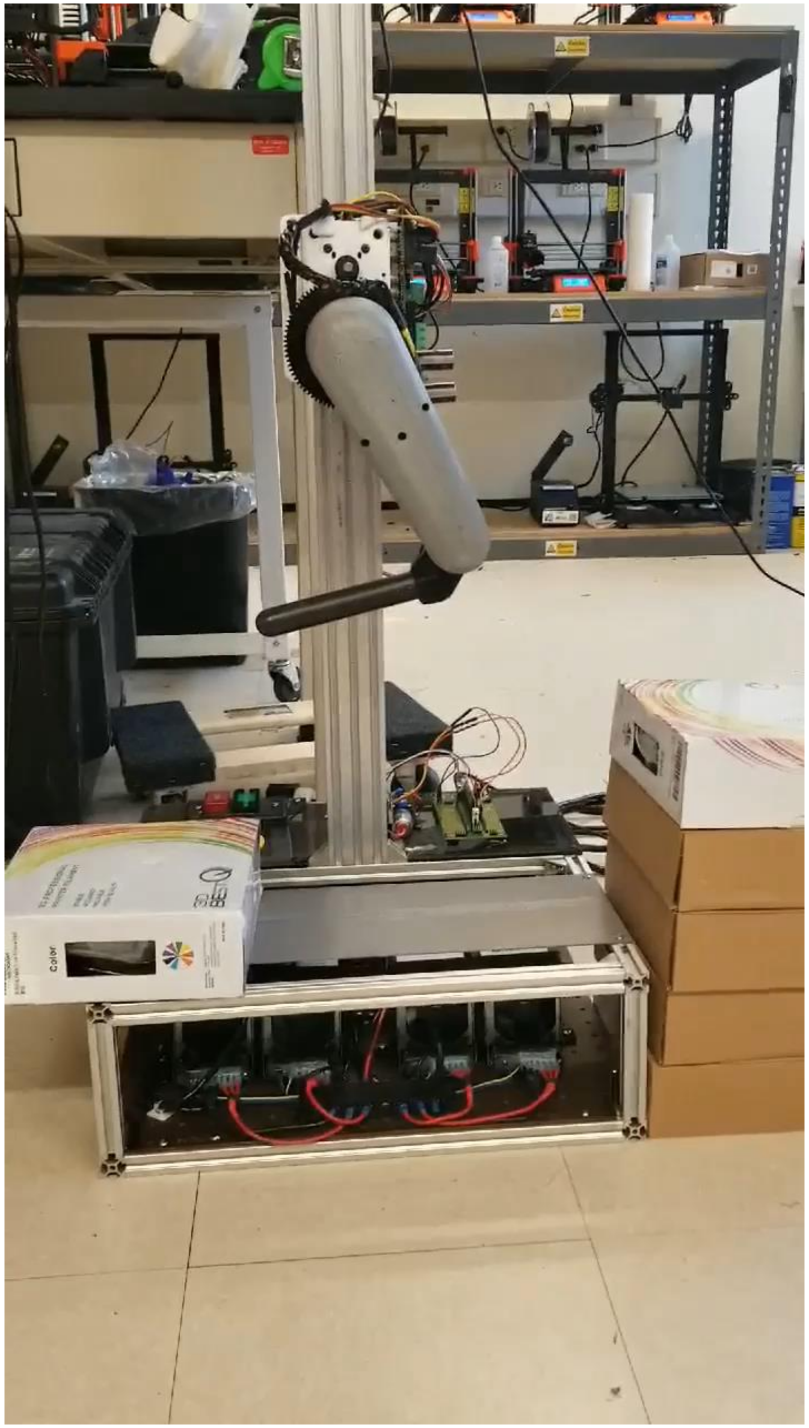
Foot Position Step Response



Motor Current Usage







Conclusion

- Future work
  - Inverse dynamics task space controller
  - Open sourcing the project files and creating documentation/tutorials
  - Improving the JoeDrive
  - Extending development platform to multiple legs

Acknowledgements

We would like to extend special thanks to:

- David Hanley
- Chuanzheng (Chad) Li