UC Berkeley Mechanical Engineering

SPROUT UP

Support You Can Carry With You

ME 239 ROBOTIC LOCOMOTION FINAL PROJECT

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Goals/ Design Requirements

A wearable assistive device for patients unable to stand up independently was designed for ME C239. Potential users include the elderly, stroke survivors and other patients with neurological or physical ailments.

Goal # 1

Assist users with limited leg strength to stand up more safely and with reduced effort.

Goal # 2

Make the wearable harness lightweight, comfortable, adjustable, and quick to don and disengage.

Goal # 3

Keep the system compact, low-profile, and autonomous so it can be worn daily in home environments.

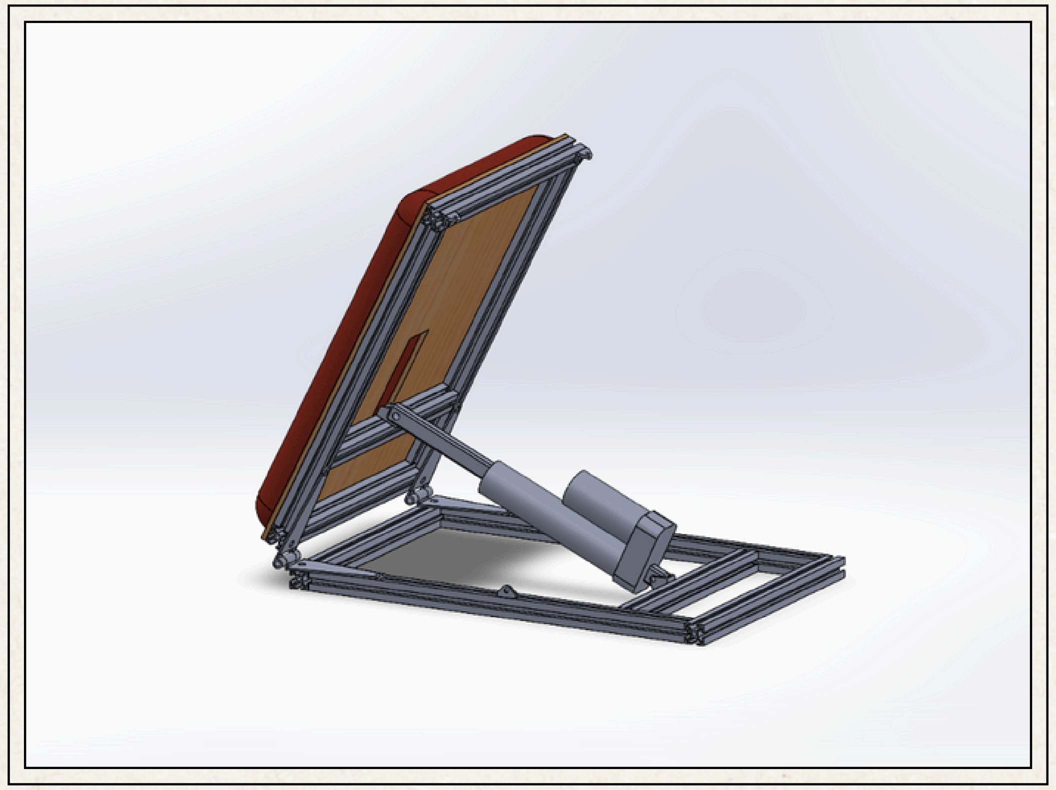
Mechanical Design

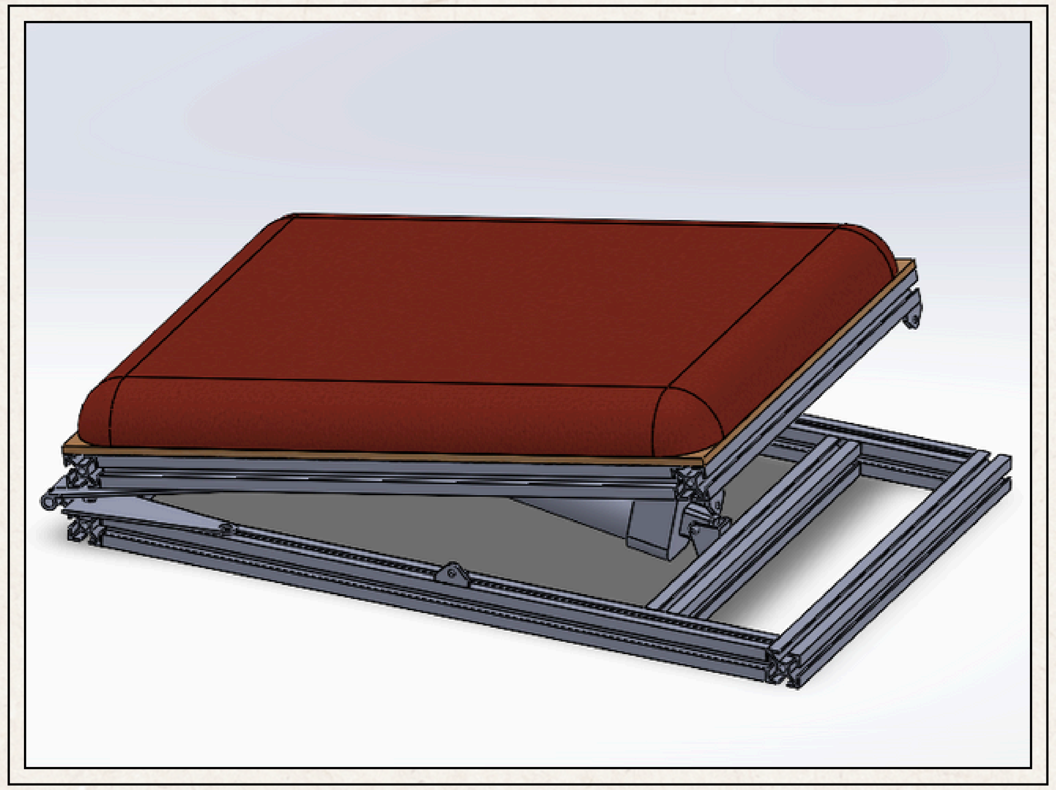
Design Overview:
- **Frame:** 2020 Aluminum extrusion
- **Platform:** Wood base layer
- **Actuation:** 12V Linear Actuator

Achievements:
- Weight: 4kg
- 60% Torque Assistance for 80 kg torso

Challenges:
- Optimizing Size, Weight, Angles
- Generating sufficient power

Problem & Future Solutions:
- High Horizontal Forces → Weld Joints
- Curved design to lower minimum angle of the seat (see appendix)



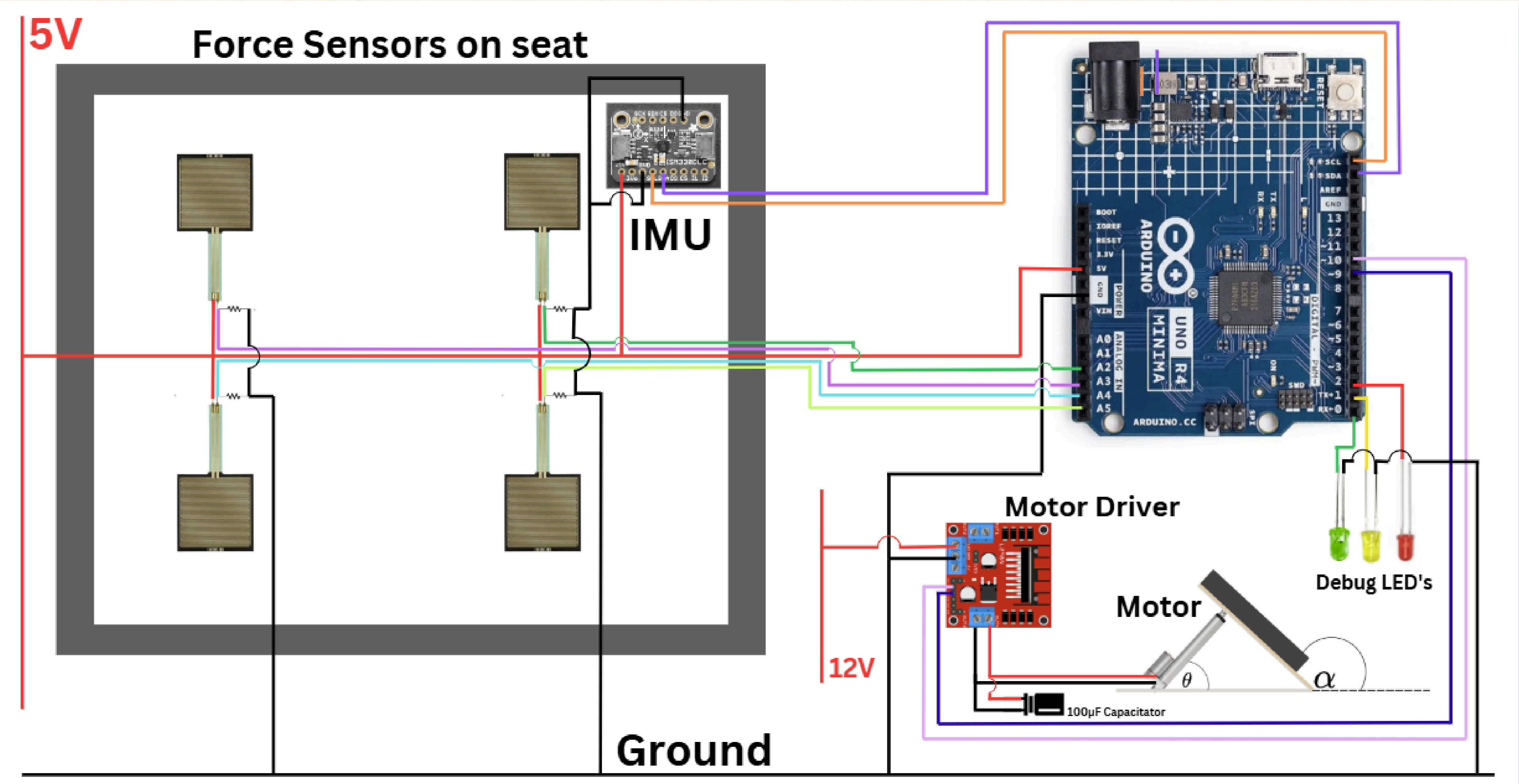


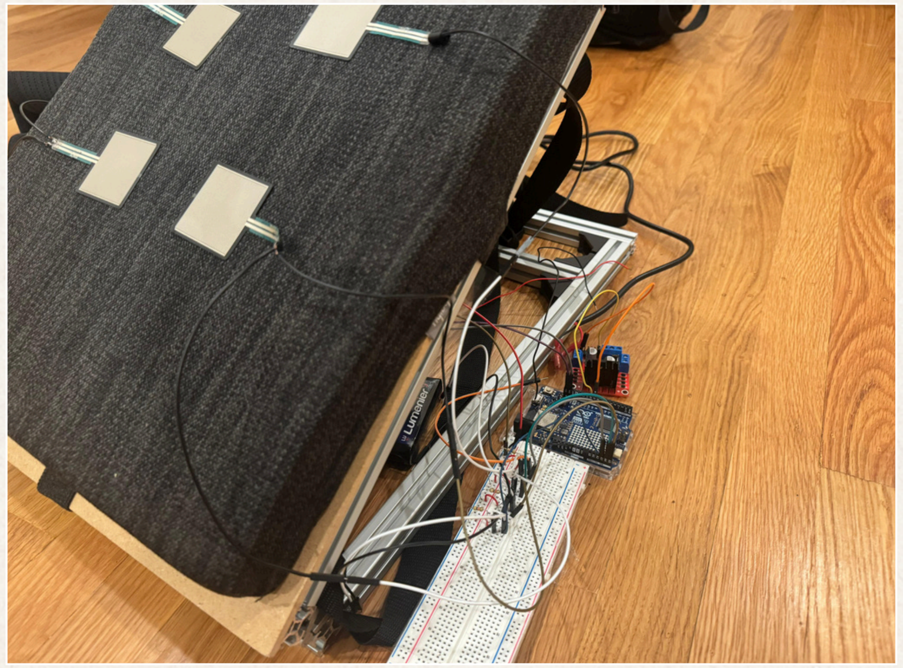
Electronic Design

Design Overview:
- **Updated circuit** to respond to data transmission issues
- **Physical implementation & debugging circuit**

Achievements:
- Full integration of electronics on prototype
- Calibrated sensors
- Drove motor for extended period of time using microcontroller

Challenges:
- Distance between components required multiple circuit boards
- Esp32 required too many dependencies and had communication issues → switched to Arduino
- Faulty hardware made full implementation hard
- Switched to perf-board and less constraining set up for prototype





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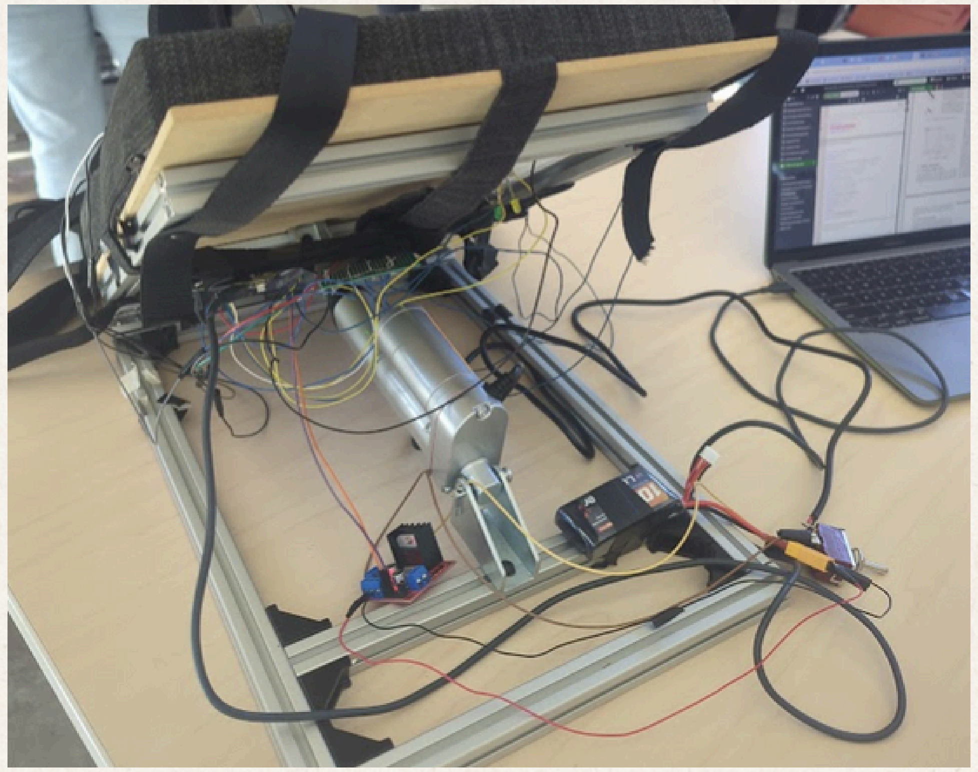


Control Logic & Modeling

Design Overview:

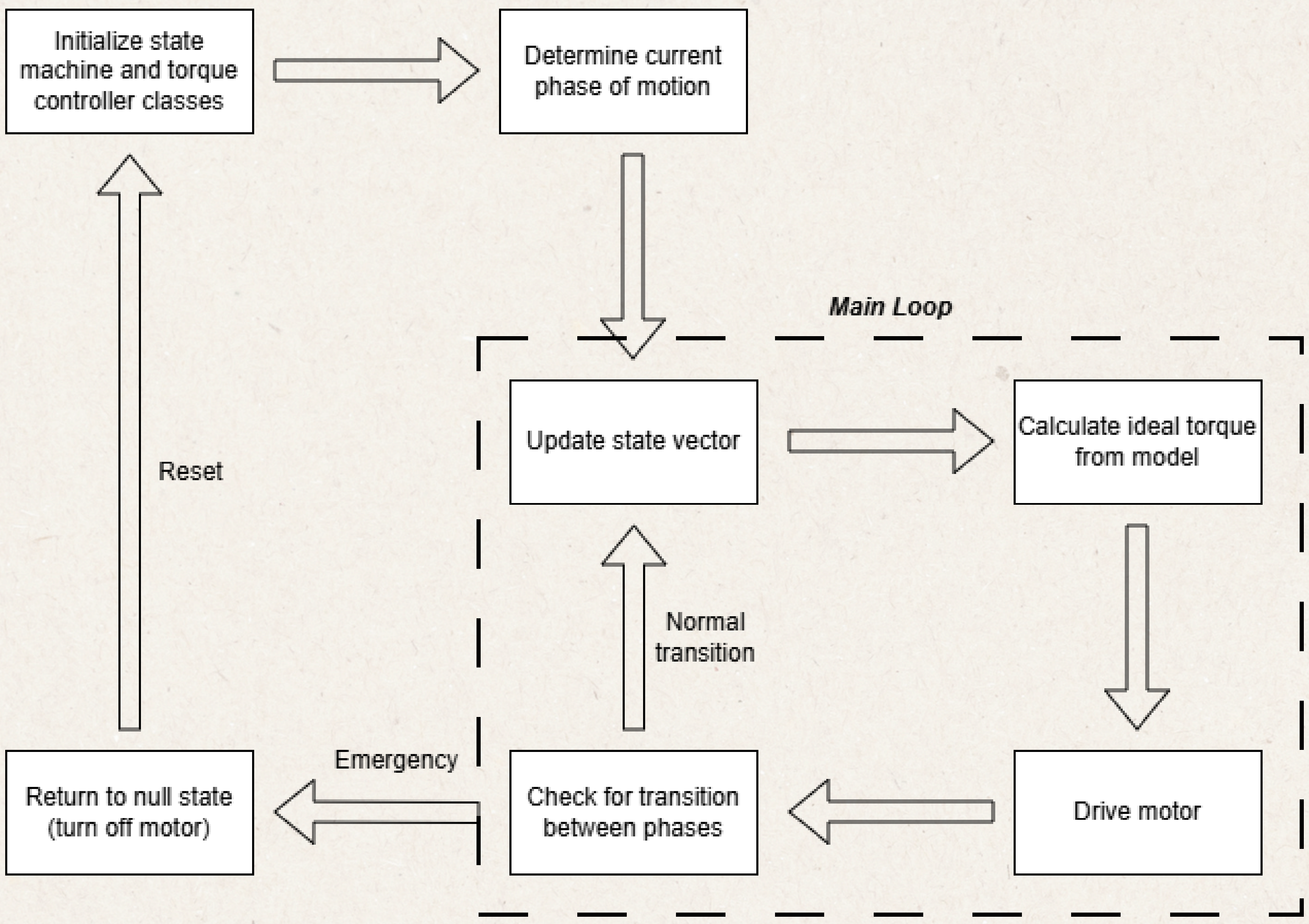
- **Controls code** finished and implemented
- **Dynamic modeling** sit-to-stand in MATLAB

Achievements:

- Autonomous state changes using sensor data
- Determined angular displacement, velocity, and acceleration of seat's motion using previous study's motion analysis
- Performed dynamic analysis to determine required force and extension of the motor during motion

Challenges:

- Downscaled controls algorithm for Arduino compatibility
- Determining the baseline measurements for the dynamic analysis



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- Autonomous state changes using sensor data
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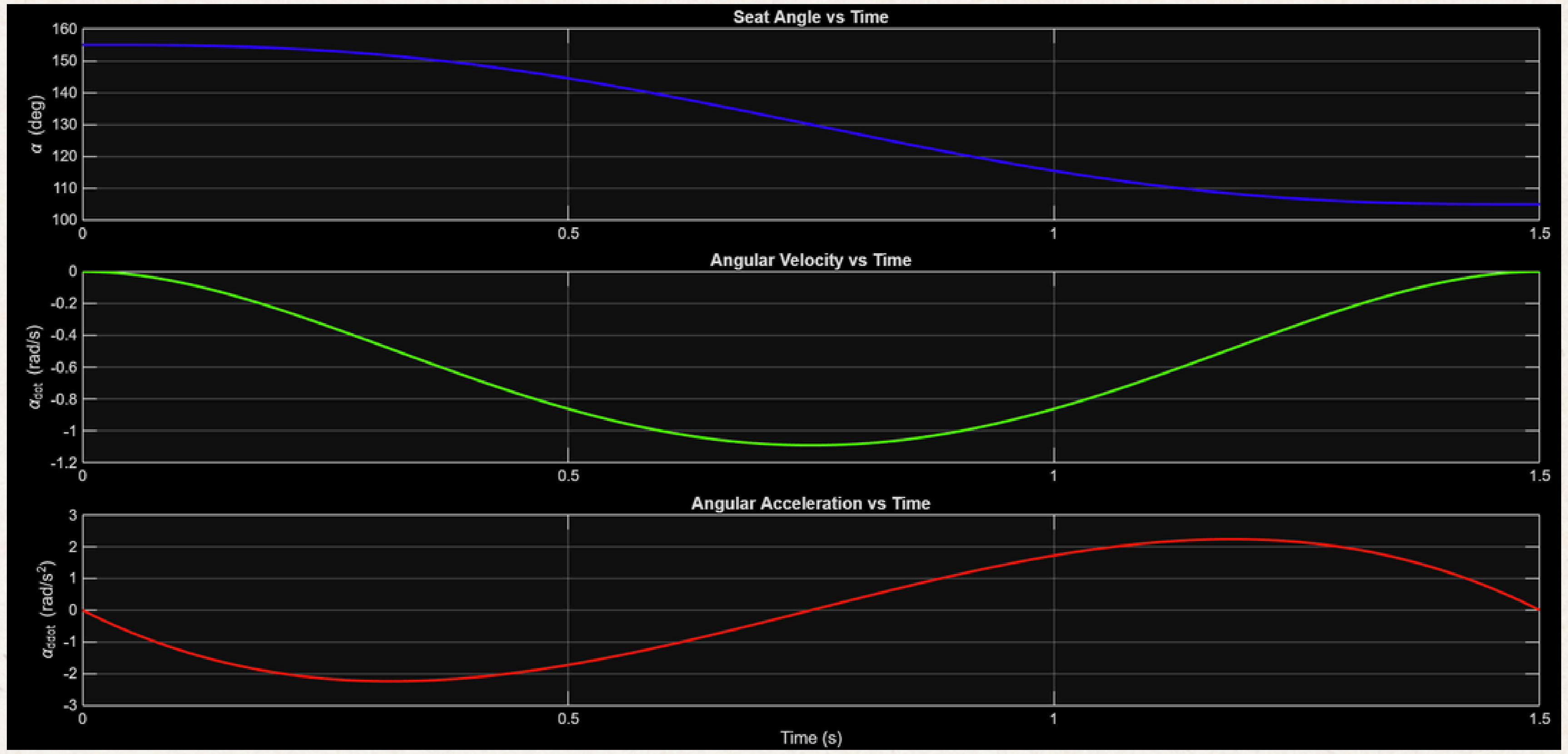
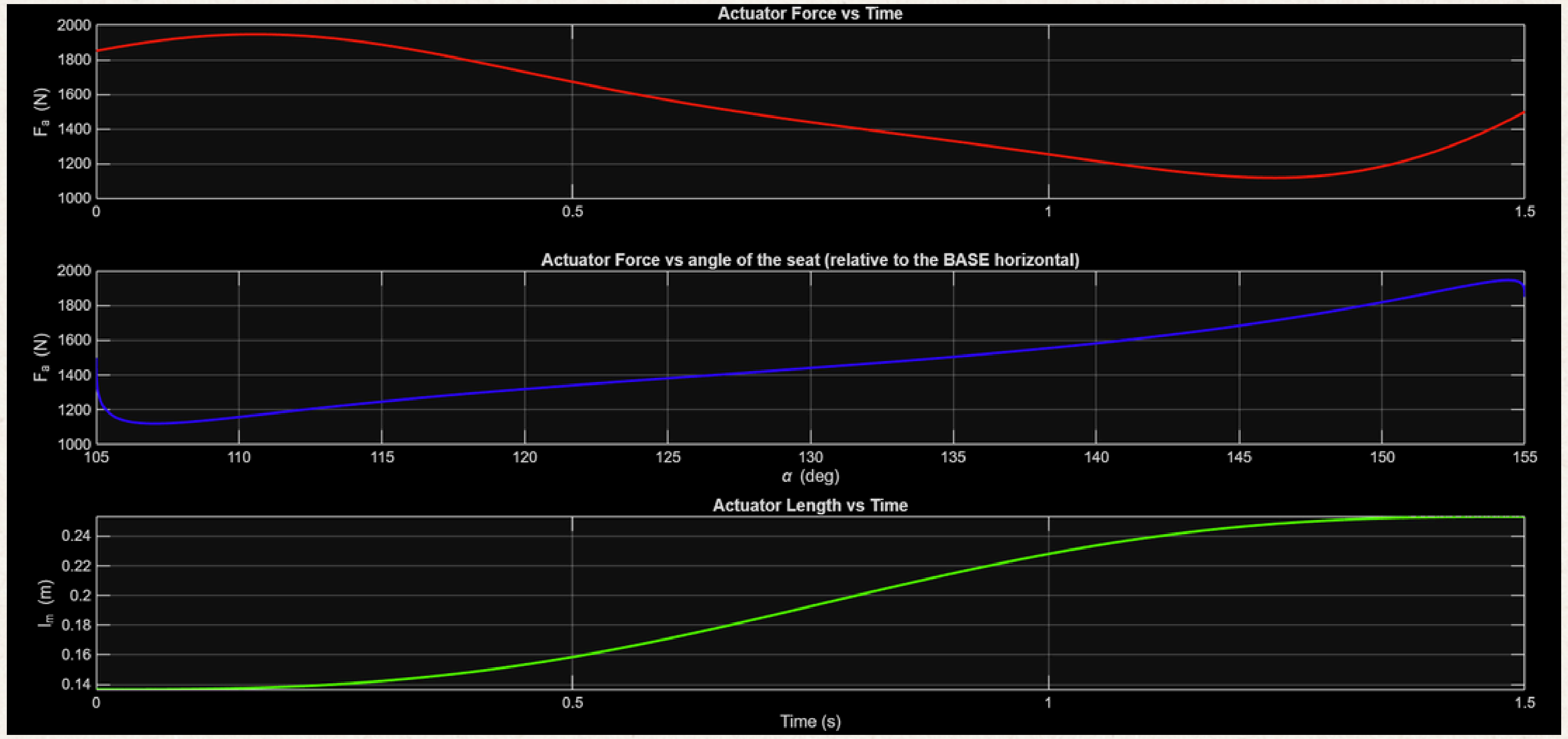
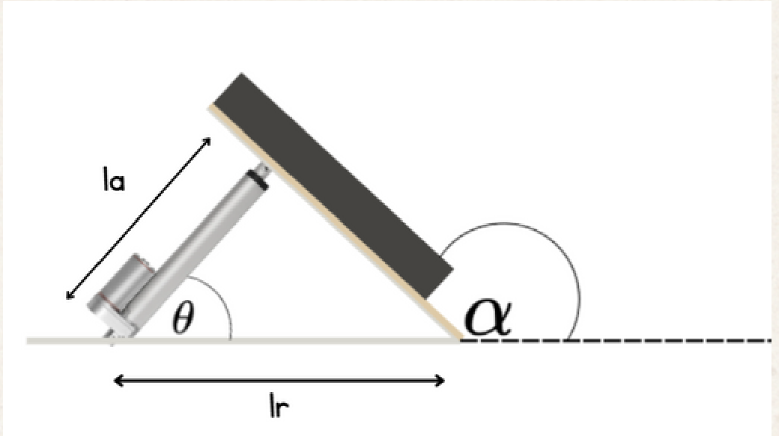
- Performed dynamic analysis to determine required force and extension of the motor during motion
- Controlled dynamics using Arduino and motor driver

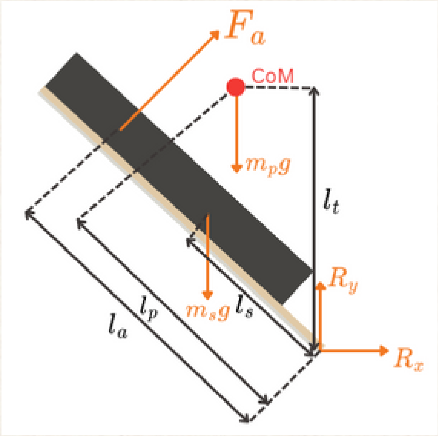
Challenges:

- Downscaled controls algorithm for Arduino compatibility (Difficulties downloading dependencies)
- Determining the baseline measurements for the dynamic analysis (measurements for different parts based on constantly changing parts)









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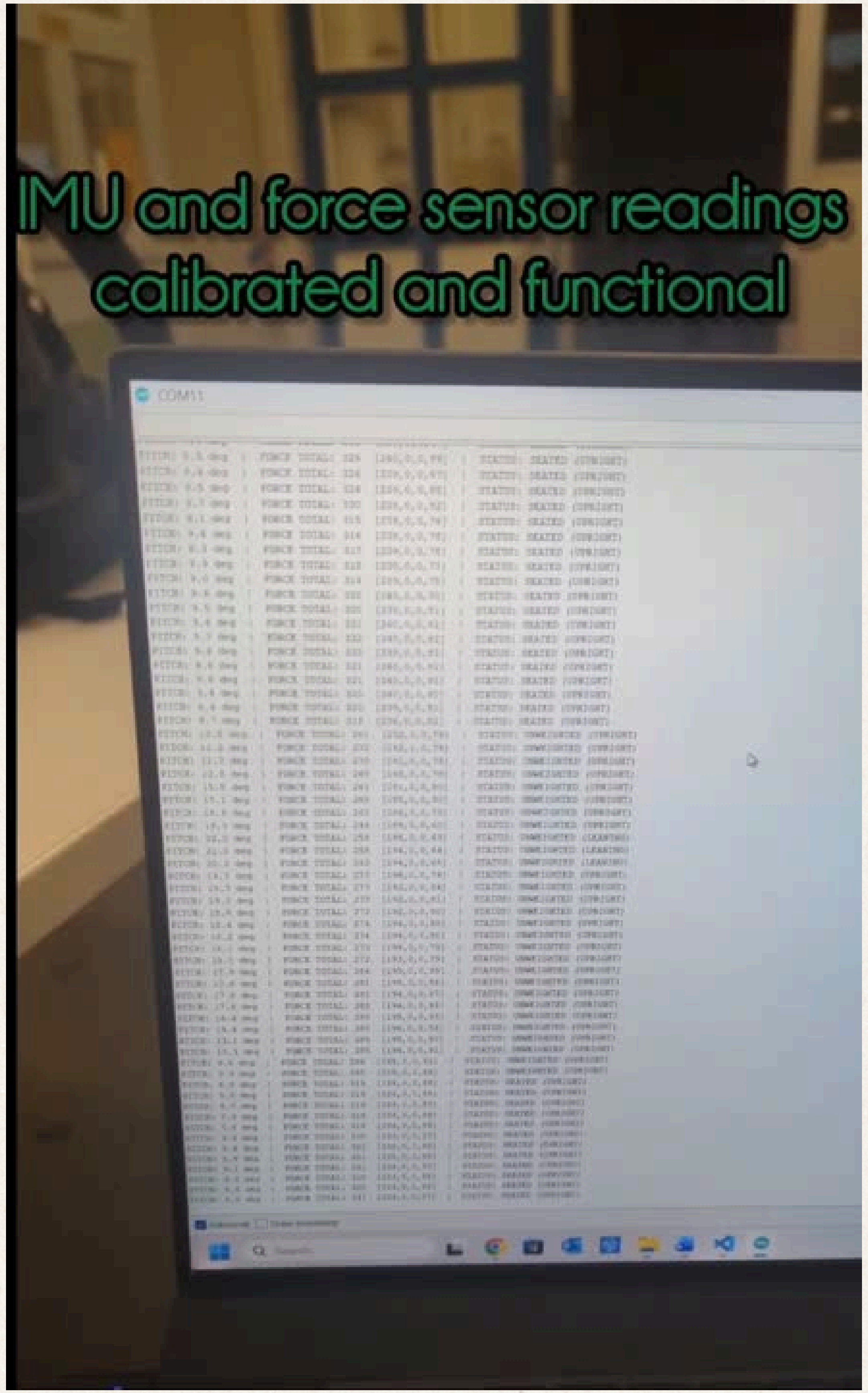
Video demo with control implementation steps

[electronics demo link]



Wearability & Ergonomics

Design Overview:

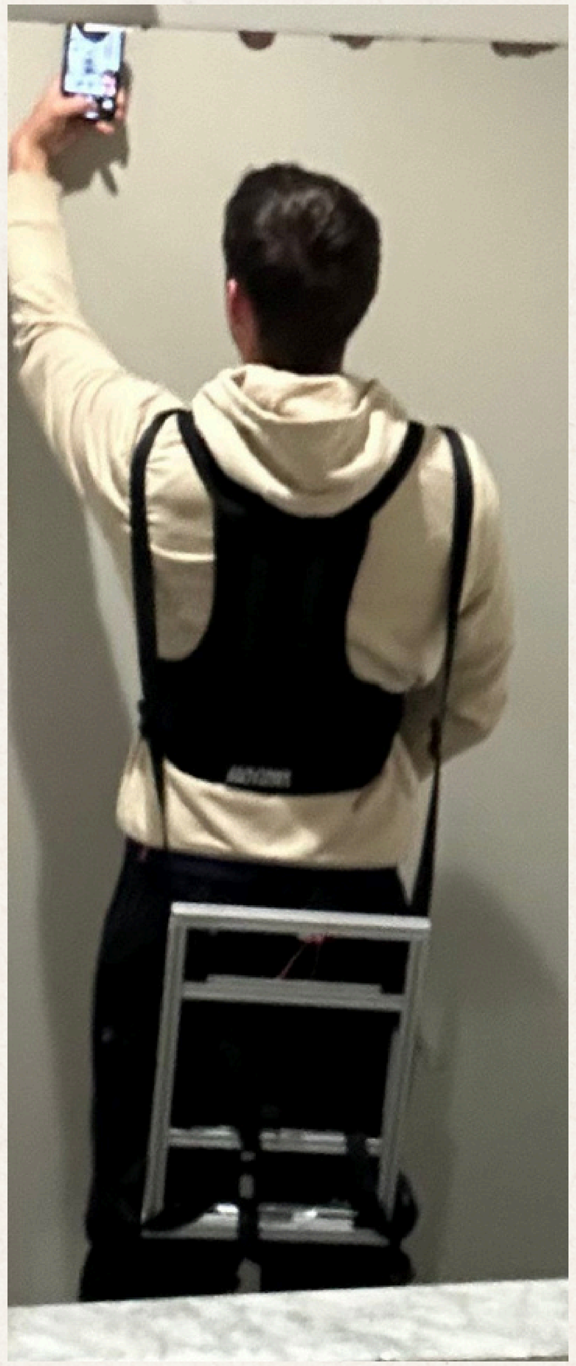
- **Torso harness** based on posture brace
- **Straps** link user to assistive seat & disengage device

Achievements:

- Padded, adjustable straps spread pressure
- Harness folds up onto lower back for disengagement

Challenges:

- Fragile → structural enhancement
- Early strap routing confusing → simplified layout and buckles



Wearable Inspiration from Arc'teryx Bora AR Backpack

- **Measurement-driven fit:** Bora AR sizes the pack by back length measured from C7 to the iliac crest, and separately sizes hipbelt/shoulder straps. This inspired our plan to treat harness fit as a structured process, not trial-and-error.

- **Hip-first load logic:** The manual states the hipbelt is the foundation of pack fitting, reinforcing our goal to route SproutUp support through a stable torso/waist interface instead of overloading the shoulders.

Bill of Materials (Wearable)

- Base harness: Off-the-shelf posture brace
- Added webbing: Nylon/polyester webbing

Multi-point adjustability: Features like load lifters, sternum strap height adjustment, and GridLock highlight how small adjustments reduce pressure hotspots across users. We mirrored this mindset in our strap layout and buckle strategy.

Soft–rigid hybrid: The Bora AR's structured elements (e.g., Tegris back panel and RotoGlide hipbelt mechanism) informed our plan to combine soft harness components with a stable frame interface for better wearability during sit-to-stand and storage modes.

Reference:

ttps://thenaturalposture.com/products/magnetic-corset-back-posture-corrector-for-men-and-women?srsltid=AfmBOoofgPpTDAPLkIkvIgFUSe32vME3IPJ542K27Esp28zqJ7Xs0ubr
https://a.co/d/9hOIcPi
https://images.arcteryx.com/pdf/s17-outdoor-bora-ar-backpack-manual-web.pdf

Wearable Harness Manufacturing & Assembly

Horizontal Strap Integration

How we built it

- Identify the left/right vertical aluminum beams on the seat frame.
- Align the horizontal straps to span across the torso interface zone.
- Create strap ends as:
    - Folded loop ends or flat strap ends with a washer sandwich.
- Mechanical attachment:
    - Use screws + washers + lock nuts to secure each horizontal strap end directly into the vertical aluminum beams.
    - This makes the horizontal strap set behave like a fixed structural interface instead of a purely soft connection.
- Confirm both sides are symmetrical in height to avoid torsional pull on the user.

Vertical Strap Integration

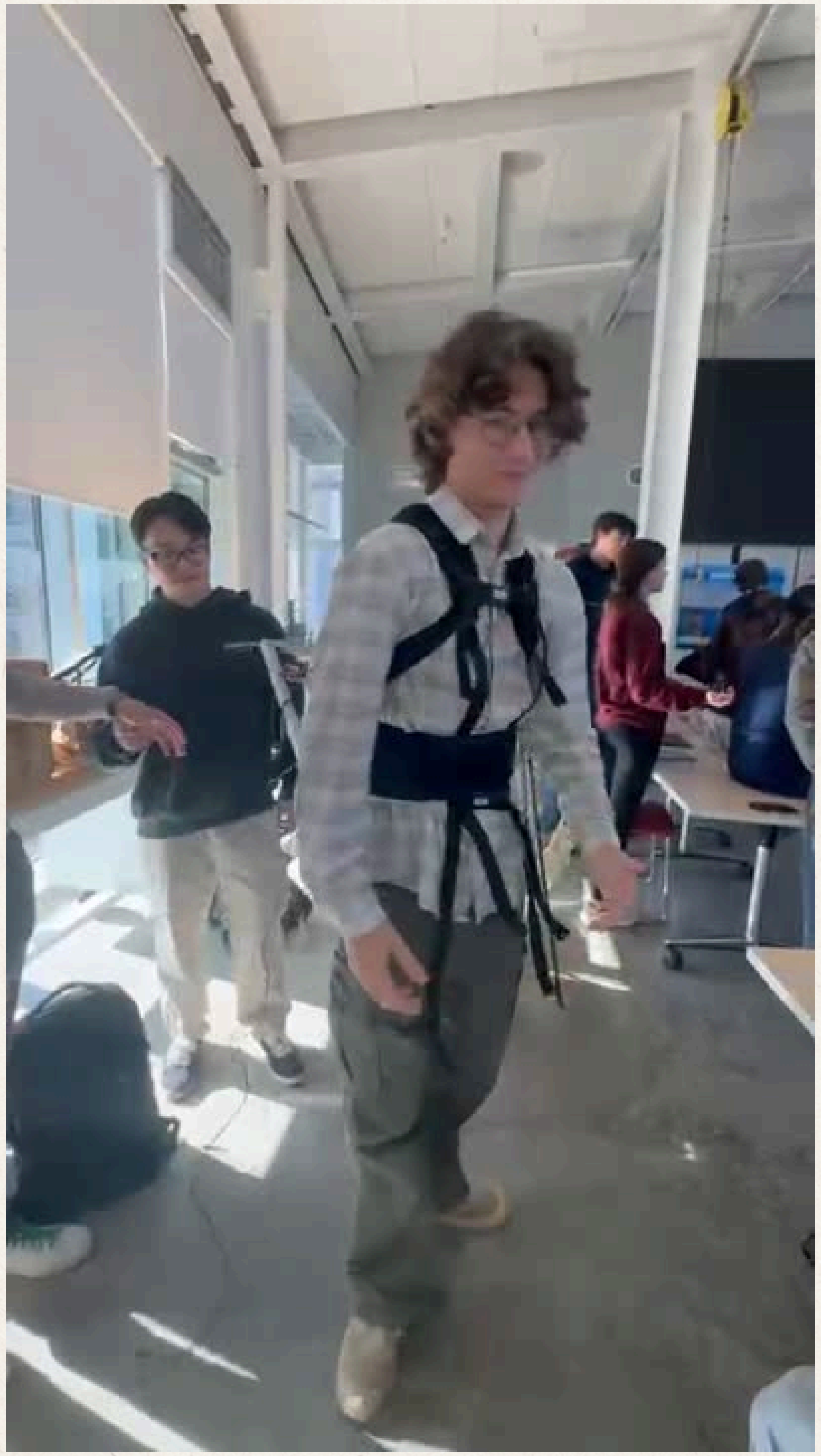
- Route each vertical strap from the brace shoulder/path region toward the frame.
- At the upper and lower frame structures/cross members,
- tie secure knots using the straps to clamp the wearable to the frame.
- The knots act as a simple, reliable retention method without requiring extra brackets.

Brace + Strap Hybridization

- The brace provides ergonomic shaping and a broad contact area.
- The cut webbing provides custom geometry tuned to the SproutUp frame.
- The system is a deliberate soft-rigid hybrid:
    - Soft interface to human body
    - Rigid anchoring to aluminum frame via screws
    - Semi-rigid retention via vertical knot points

Video Demo Wearability

wearable demo link



Potential improvements

- Consider additional safety measures
  - There is no precaution for the user falling forward in this design
- Iterate on the prototype
  - Can be drastically sized down
  - Further improve on the electronics integration to remove clutter
  - Stronger frame (hinges) will result in the possibility to set up the linear actuator in a flatter orientation, as the frame will be able to take more force
  - Curved frame will also allow for smaller fold away angle (see Appendix)
- ...

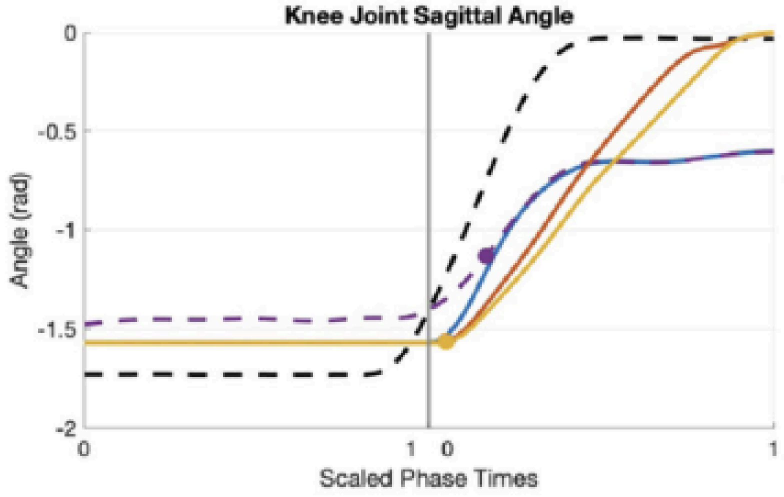
Thank you!!

See Appendices for Additional Information and Calculations

Appendix: Dynamics

1) Defining ideal trajectory

implemented a set ideal trajectory for the knee angle based on sit-to-stand data from literature:



(see doi: 10.3389/fnbot.2024.1348029)

We used a polynomial curve fit of this idealized data to get our position input

Polynomial Curve Fit (poly3)
f(x) = p1*x^3 + p2*x^2 + p3*x + p4

Coefficients and 95% Confidence Bounds

	Value	Lower	Upper
p1	-17.8753	-22.3116	-13.4389
p2	83.3272	59.9077	106.7467
p3	-56.4466	-96.3963	-16.4969
p4	-97.1419	-119.0928	-75.1909

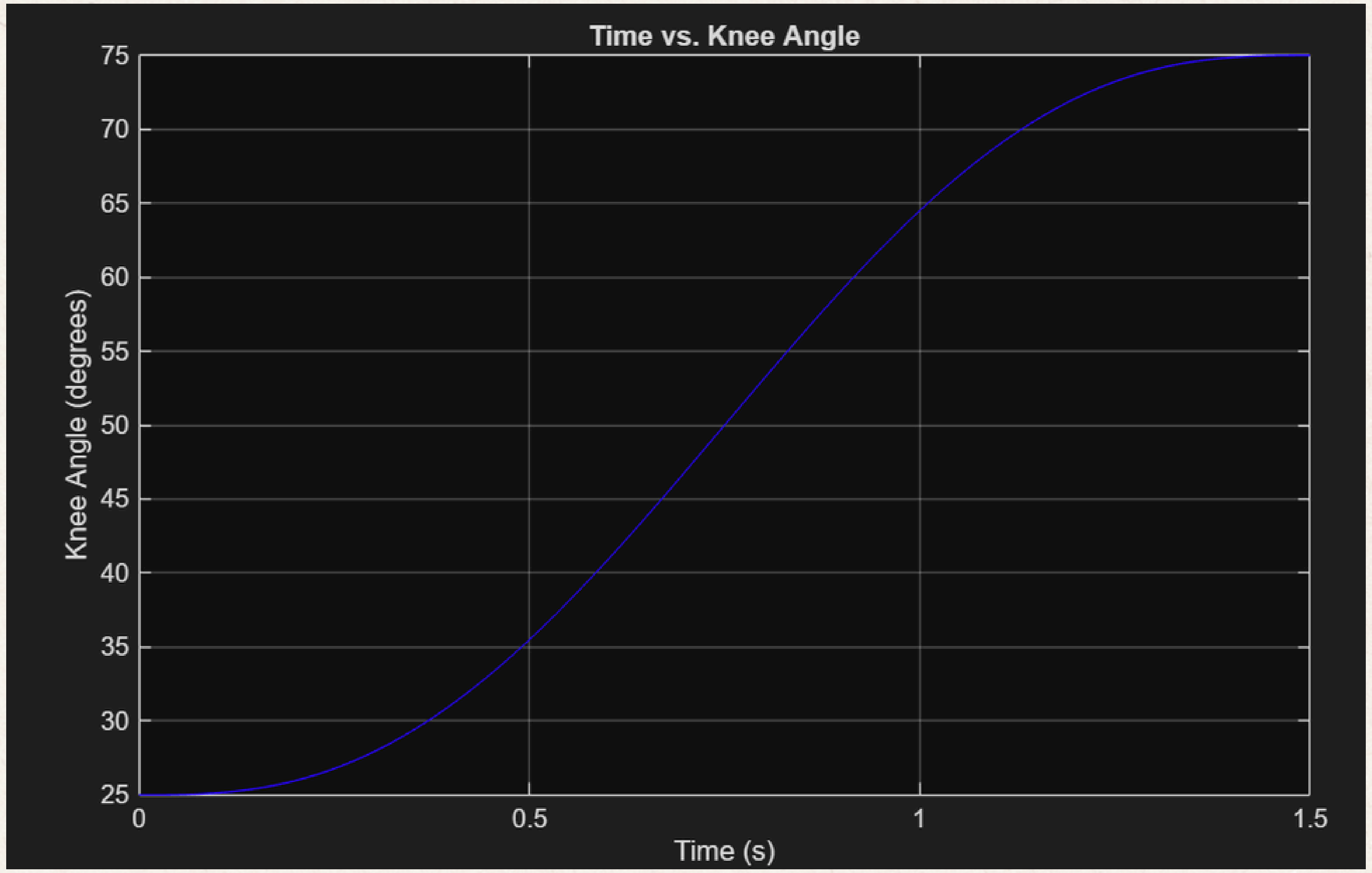
=> $\theta(t) = -17.8753t^3+83.3272t^2-56.4466t-97.1419$

We iterated and ended up using an S-curve fit of the idealized data which showed better results.

$$p(s) = 10s^3 - 15s^4 + 6s^5$$

We then derived this equation to get velocity and acceleration.

$$\dot{p}(s) = (30s^2 - 60s^3 + 30s^4)/t_{\text{end}} \quad \ddot{p}(s) = (60s - 180s^2 + 120s^3)/t_{\text{end}}^2$$



We defined a set trajectory from 25 to 75 degrees and used linear interpolation to map the knee angle θ.

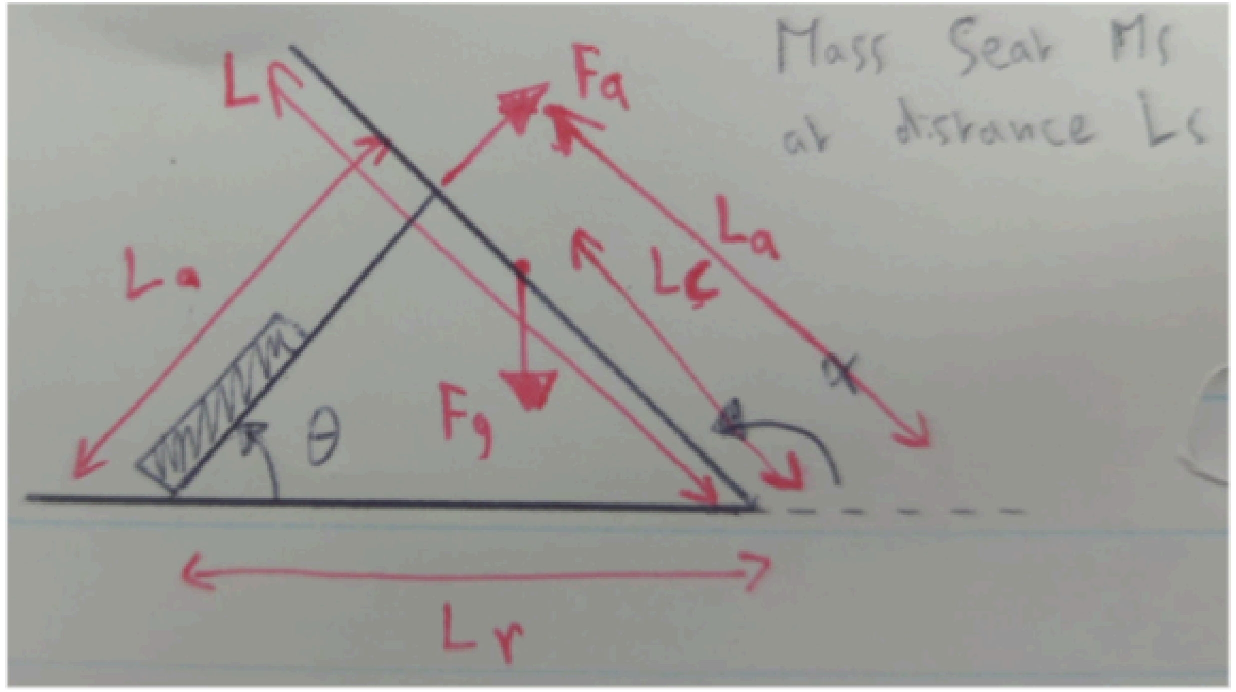
$$\theta(t) = \theta_{\text{start}} + (\theta_{\text{end}} - \theta_{\text{start}})\, p(s)$$

Transferring this to a more convenient angle α ($\pi - \theta$) gave us the input graph for our generalized coordinate. We derived the angular velocity and acceleration as well:

Appendix: Dynamics

2) Seat kinematics

With the kinematic trajectory set up and the geometry of our prototype known we went on to define the kinematics of the system:



This free body diagram shows the actuator's forces as well as the person sitting on the seat.

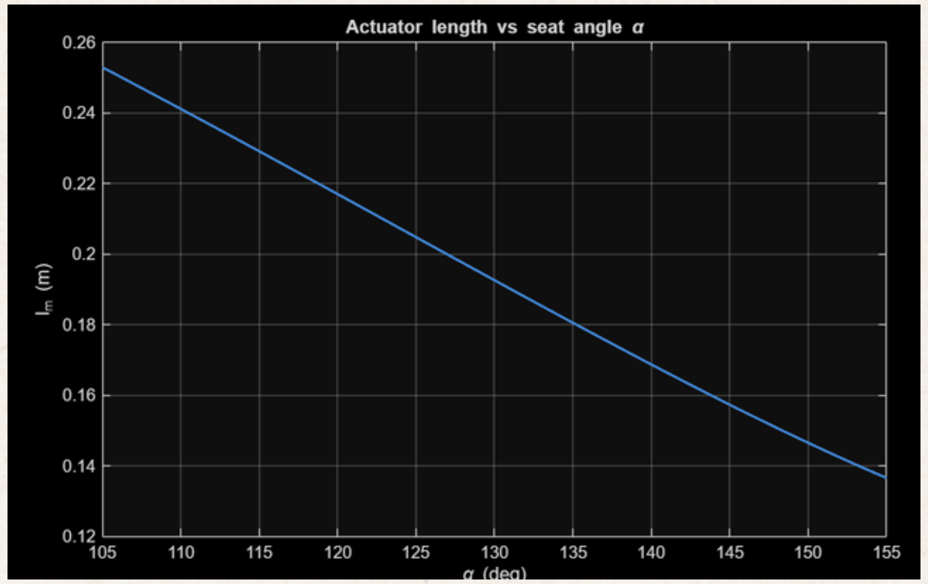
We can derive an equation for the actuator length (using the law of cosines) as well as the mechanical transmission between the actuator and set with respect to our generalized coordinate α.

$$l_m(t) = \sqrt{l_a^2 + l_c^2 + 2 l_a l_c \cos\alpha(t)}$$

$$\theta_{\text{mech}}(t) = \arcsin\left(\frac{l_c}{l_m(t)} \sin\alpha(t)\right)$$

Appendix: Dynamics

3) Lagrangian dynamics & force graphs



Actuator length vs angle (additional graph from our model)

We calculate the potential energy of the user and the seat and derive a generalized gravity term with respect to our generalized coordinate α.

$$U(\alpha) = F_g\left(l_c \sin\alpha + l_t\right) + m_s l_s g \sin\alpha \qquad G(\alpha) = \frac{\partial U}{\partial \alpha} \approx \text{gradient}\left(U(\alpha), \alpha\right)$$

We set up the linear Jacobians of the seat and person center of mass, the rotational inertia about the pivot point of the linear actuator

$$J_{vs}(\alpha) = \begin{bmatrix} -l_s \sin\alpha \\ l_s \cos\alpha \end{bmatrix}, \quad J_{vp}(\alpha) = \begin{bmatrix} -l_c \sin\alpha \\ l_c \cos\alpha \end{bmatrix} \qquad I_{ws} = \frac{1}{3} m_s l_s^2.$$

and use this to derive an equation for total scalar inertia about the pivot point M.

$$M = m_s l_s^2 + I_{ws} + m_p l_c^2 + I_{wp}.$$

We neglect the coriolis, as this has a minor effect and would complicate the model, and end up with the following dynamic equation:

$$M\ddot{\alpha} + G(\alpha) = \tau(\alpha, \ddot{\alpha}) \;, \qquad \tau(t) = M\ddot{\alpha}(t) + G(\alpha(t))$$

4) Mapping torque to force

The geometric relation between the actuator force and joint torque is expressed as follows

$$\tau(t) = F_a(t)\, l_a \sin\theta_{\text{mech}}(t) \cos\alpha(t)$$

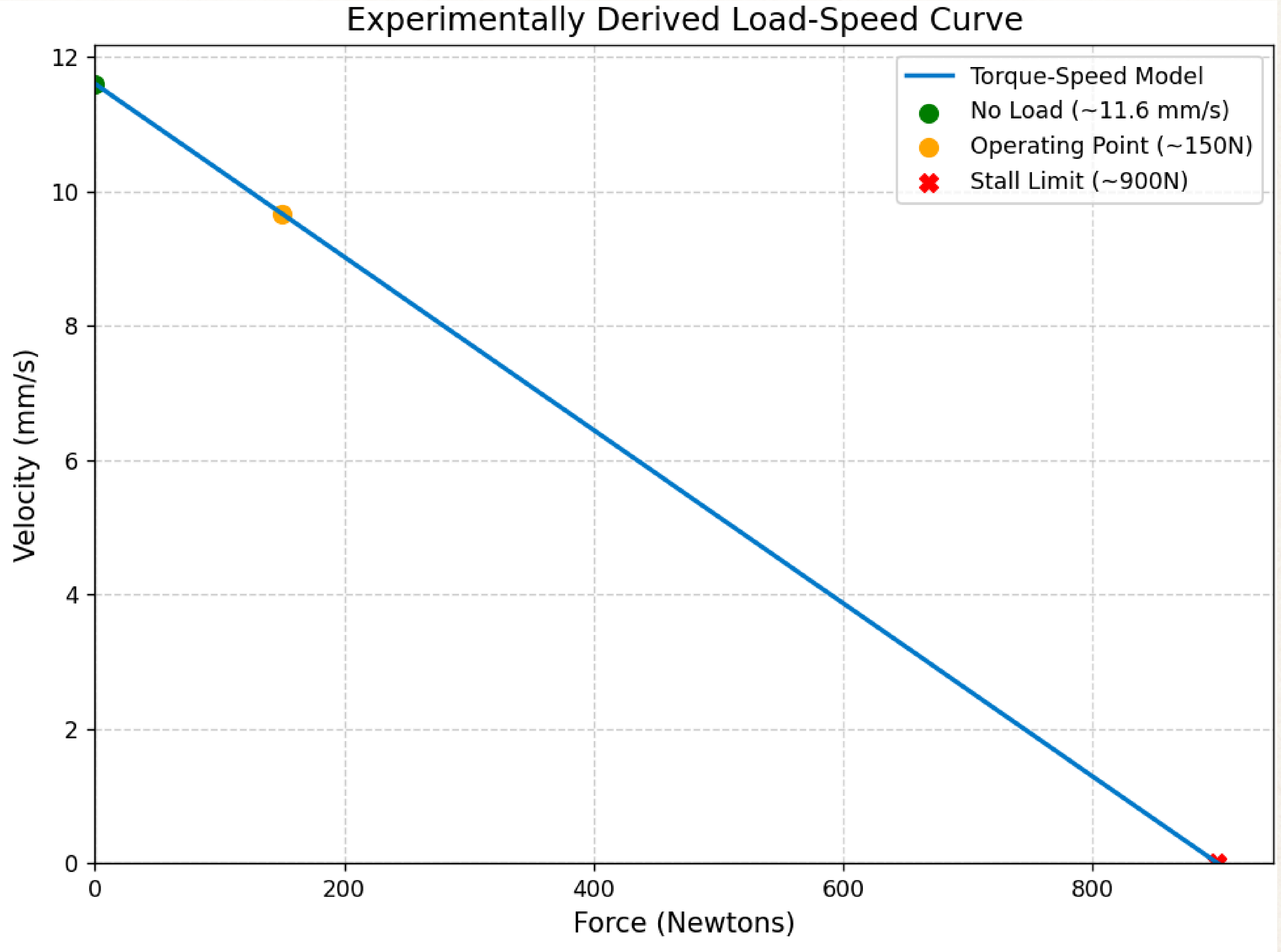
Which results in the following derived equation for the linear actuator force

$$F_a^{\text{rigid}}(t) = \frac{\tau(t)}{l_a \sin\theta_{\text{mech}}(t) \cos\alpha(t)}$$

The results were smoothed and made more realistic by adding a smooth reciprocal to avoid singularities when the denominator reaches small values. Which gives the graphs on slide 5:

Appendix: Motor Characterization

Tested actuator at no load and max load to approximate load-speed curve (in linear direction)



From 12V curve, we found a speed (mm/s) to PWM value ratio of approximately 0.0379 at our test load. We used this to code open-loop curve-following behavior when our sensors for our feedback variable (the seat angle) weren't working well.

Appendix: Technical Specifications

Motor:

- 12V
- 1000N
- 200mm stroke
- 14mm/s at base speed

**note that we found slightly different motor characteristics when testing, as shown in the previous slide

Pressure Sensors:

- 5V
- Used Force sensing resistors (FSR) in parallel with a 43KOhm → measure the voltage reading of the FSR to determine how much for we are reading based on voltage division

Motor driver:

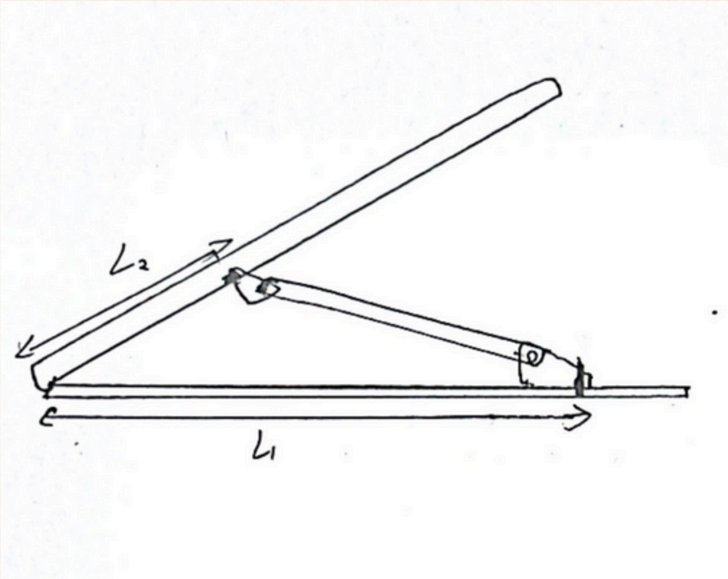
- Can connect to 12V or 5V power source, with input pins to change direction and map input voltage to output PWM signal
- Functions as a 2 channel H-Bridge, with the possibility to connect two motors

IMU:

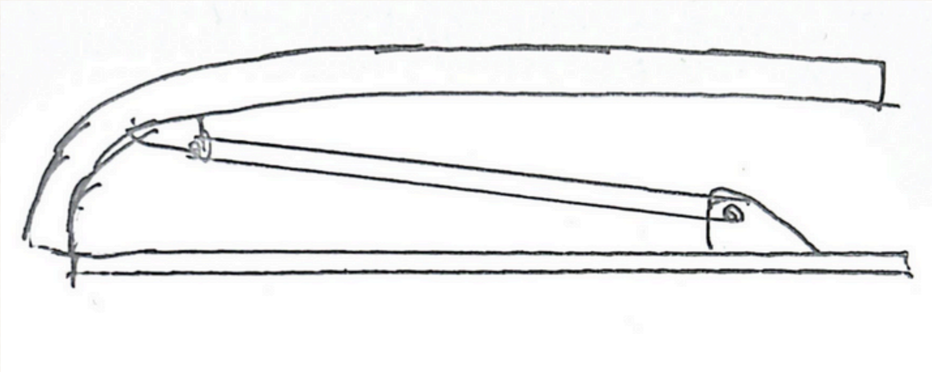
- 5V
- used to detect seat angle and as feedback variable in the control loop

Appendix: Wearable Diagrams

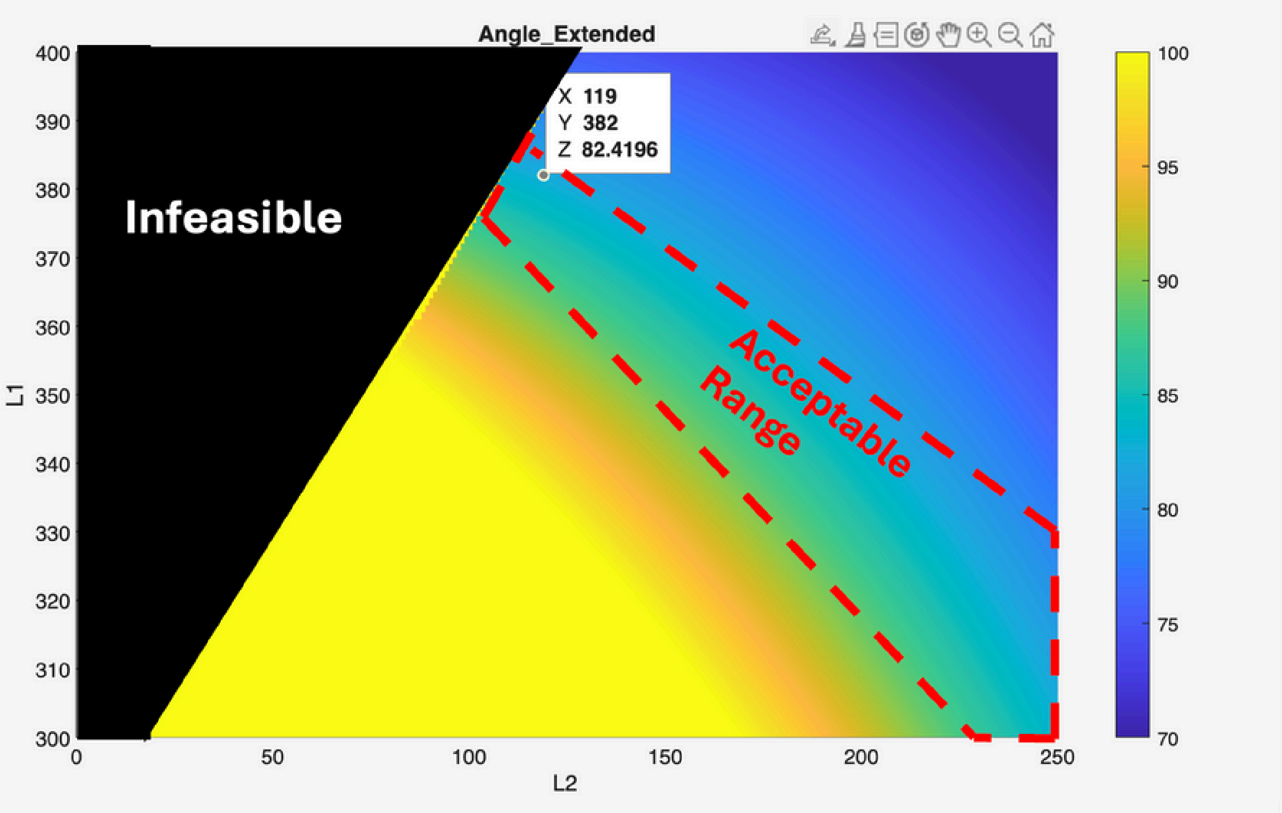
Appendix: Seat Optimization

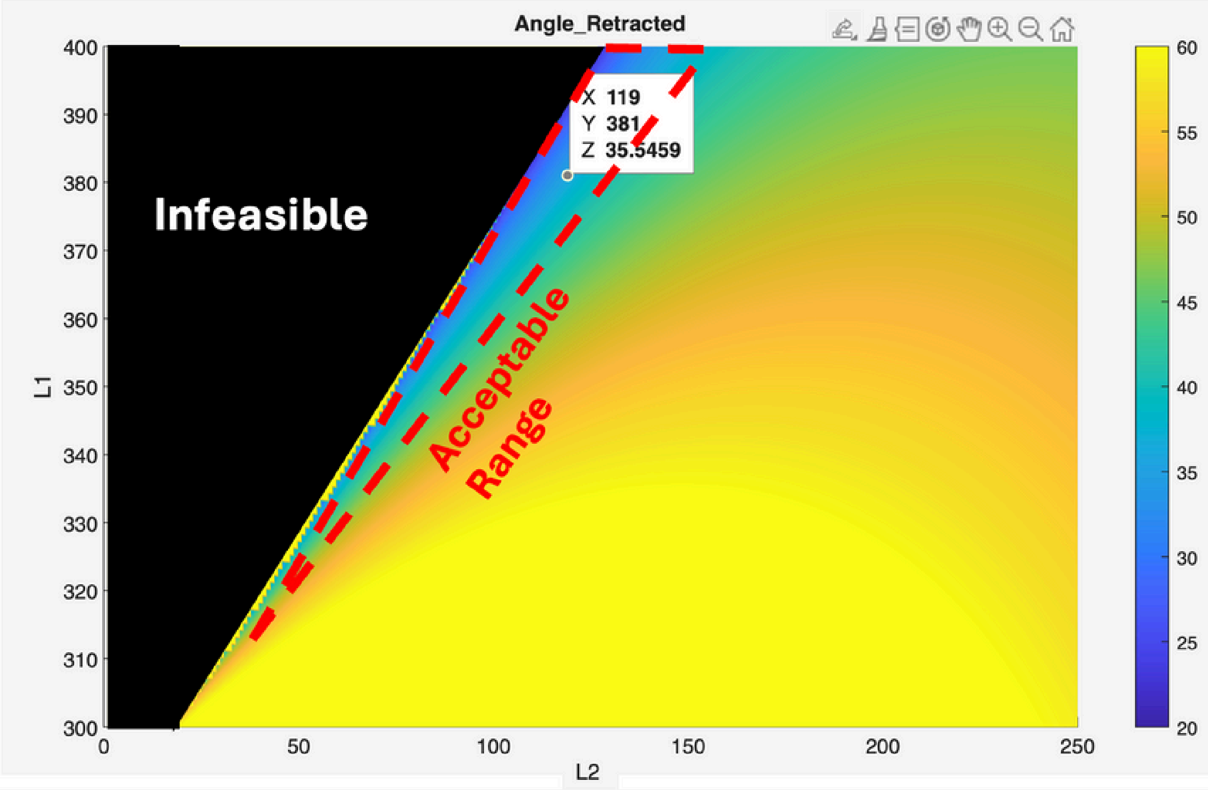


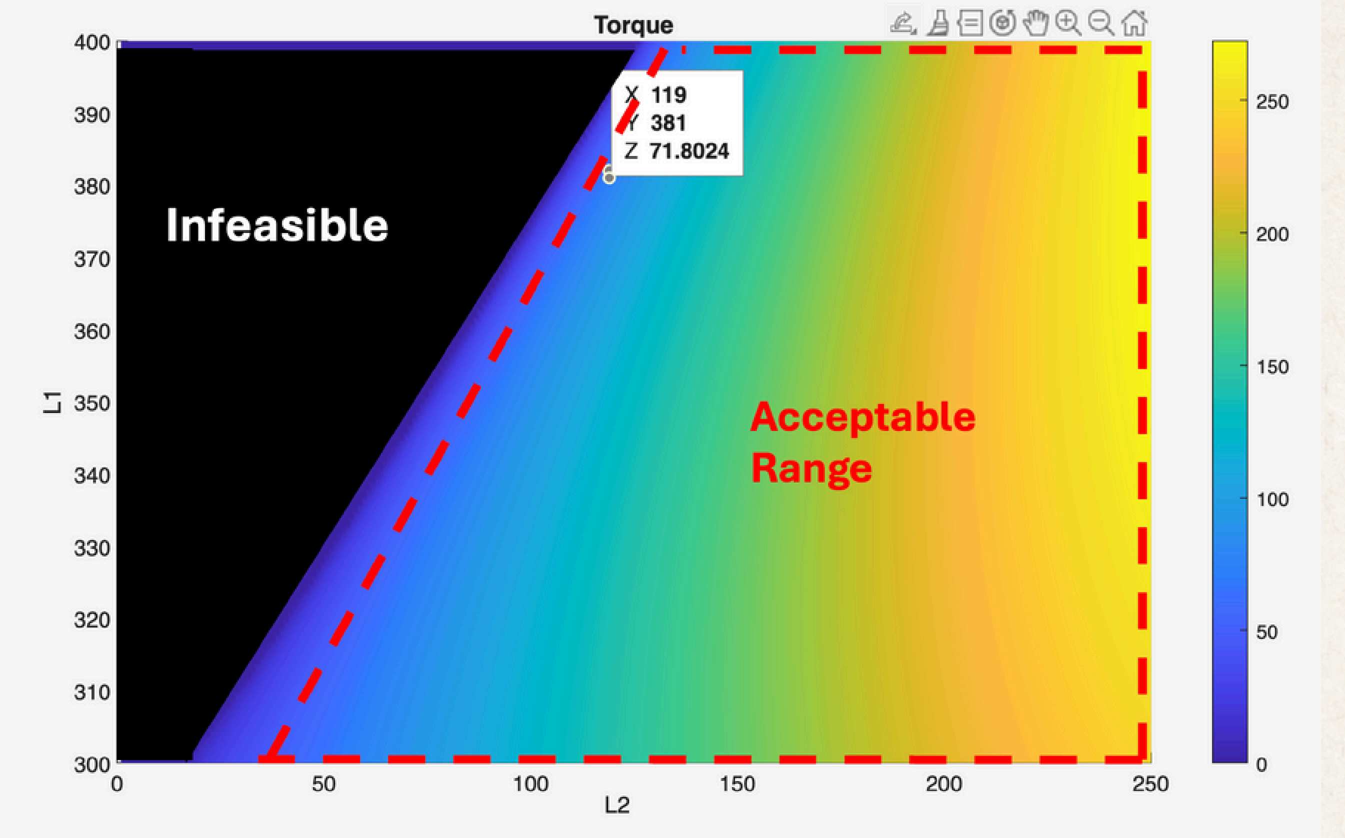
Current design:
Minimum Angle = 35 Degrees
Maximum Angle = 82 Degrees
Torque = 72 Nm (1.2 FOS)



How to improve Minimum Angle:
Curved Metal Frame
(0 Degree Seat)



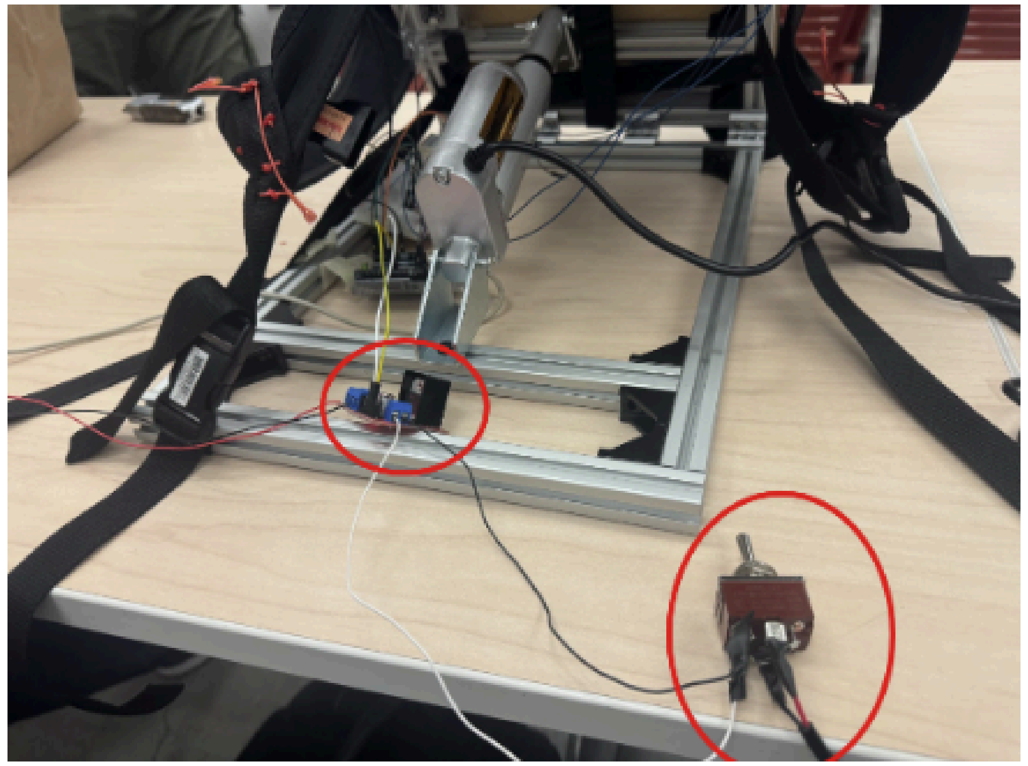




Appendix: Implementation Steps

<u>Hardware implementation & debugging:</u>

- MVP model moving the seat with a switch works
- Low-level arduino controls move the seat using motor control through the H-bridge works briefly
- Faulty H-bridge identified is diagnosed as the issue: the linear actuator command runs forward, but won't in reverse. We try implementing temporary solutions for motor control testing
    - Patch: You can use input pairs to control the H-bridge, the switch runs



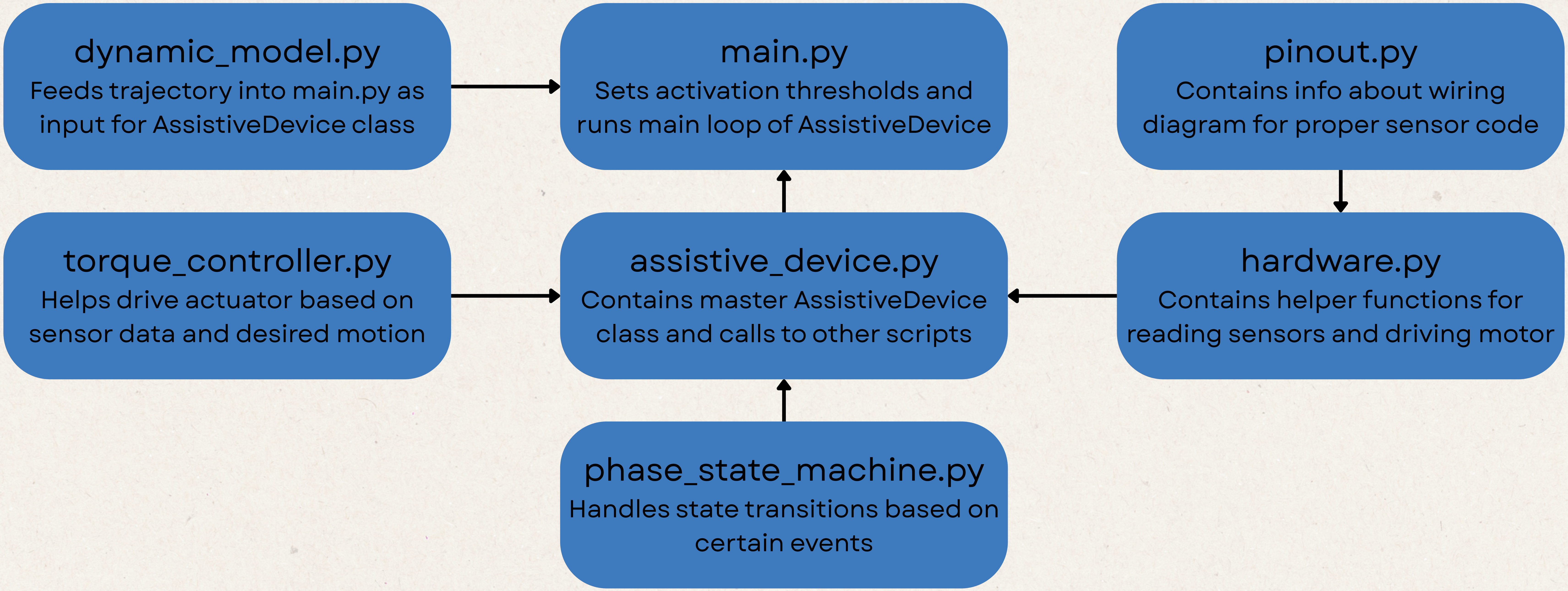
- Got it running in an open loop with the motor following the idealized curve
    - Used Analog outputs to control the speed of the motor:
        - Determined the relationship between PWM signal and motor speed, which we used to output the idealized standing model

<u>Added steps since presentation:</u>

- Added the force thresholds for autonomous actuation back in the controls - fixed!
- Control loop reading IMU data, adapting torque to match the idealized curve
    - IMU isn't being read, but it is implemented in the logic

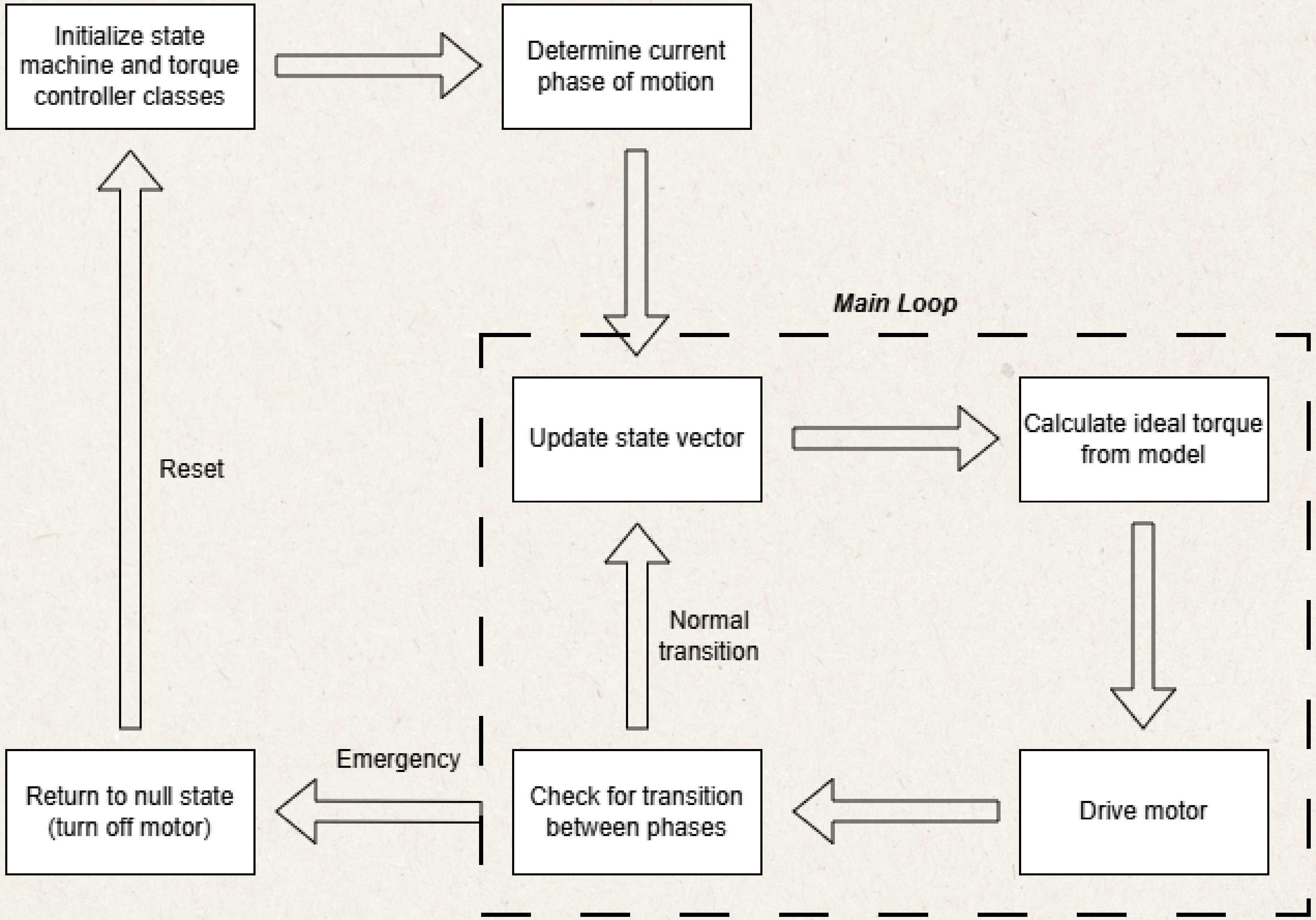
Appendix: Code Walkthrough

Here is a breakdown of our rigorously made, ideal code



Appendix: Code Walkthrough

For our demonstration, the code we ended up using didn't follow our idealized phase diagram (right) due to hardware/sensor constraints. We did, however, have a trigger to the sit-to-stand motion phase based on the force sensors on the seat, and a trajectory to follow in that phase. The main thing we lacked was robust detection of the current state.



Citations

Research/resources we used?

01 Lau JCL and Mombaur K (2024) Can lower-limb exoskeletons support sit-to-stand motions in frail elderly without crutches? A study combining optimal control and motion capture. Front. Neurorobot. 18:1348029.

02 Bill of materials: (Link)