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Design Review 6

Team 515 – Controllable CVT Device

Kemani Harris, Aaron Havener, Jacob Hernandez, Aliya Hutley, and Cade Watson

04/03/2025

Meet Team 515

Kemani Harris
Dynamics Engineer

Aaron Havener
Controls Engineer

Jacob Hernandez
Design Engineer

Aliya Hutley
System Engineer & POC

Cade Watson
Materials Engineer

FAMU-FSU College of Engineering

Sponsor & Advisor

Florida Agriculture & Mechanical University and Florida State University

National Science
Foundation

Dr. Carl Moore Jr.
Associate Professor

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Engineering

Objective

The objective of this project is to enhance robotic education by creating a device using continuously variable transmissions (CVTs). The device is intended to utilize computer control and move through various positions to produce accurate output motion.

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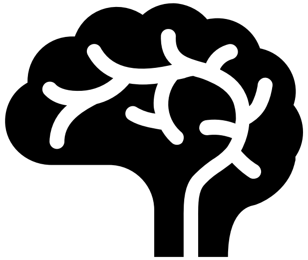
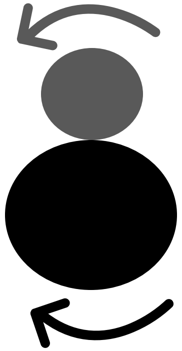
Cade Watson

Key Goals

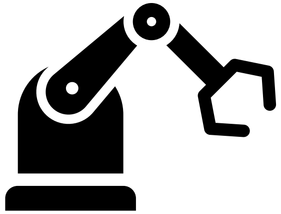
The primary goal of this project is to utilize CVT technology to present to STEM-curious students:



General autonomous robotic technology



The mechanical principle of CVT's



The use of CVT's in robotics

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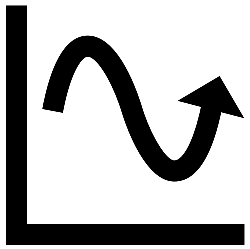
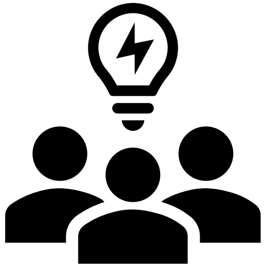
Key Goals

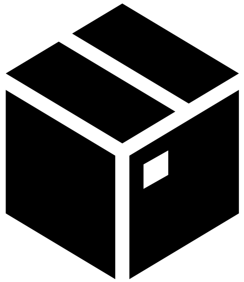
Other key design goals are:



Precise, autonomous two-dimensional movement



Customizable, well-displayed, and engaging output



Use in multiple locations

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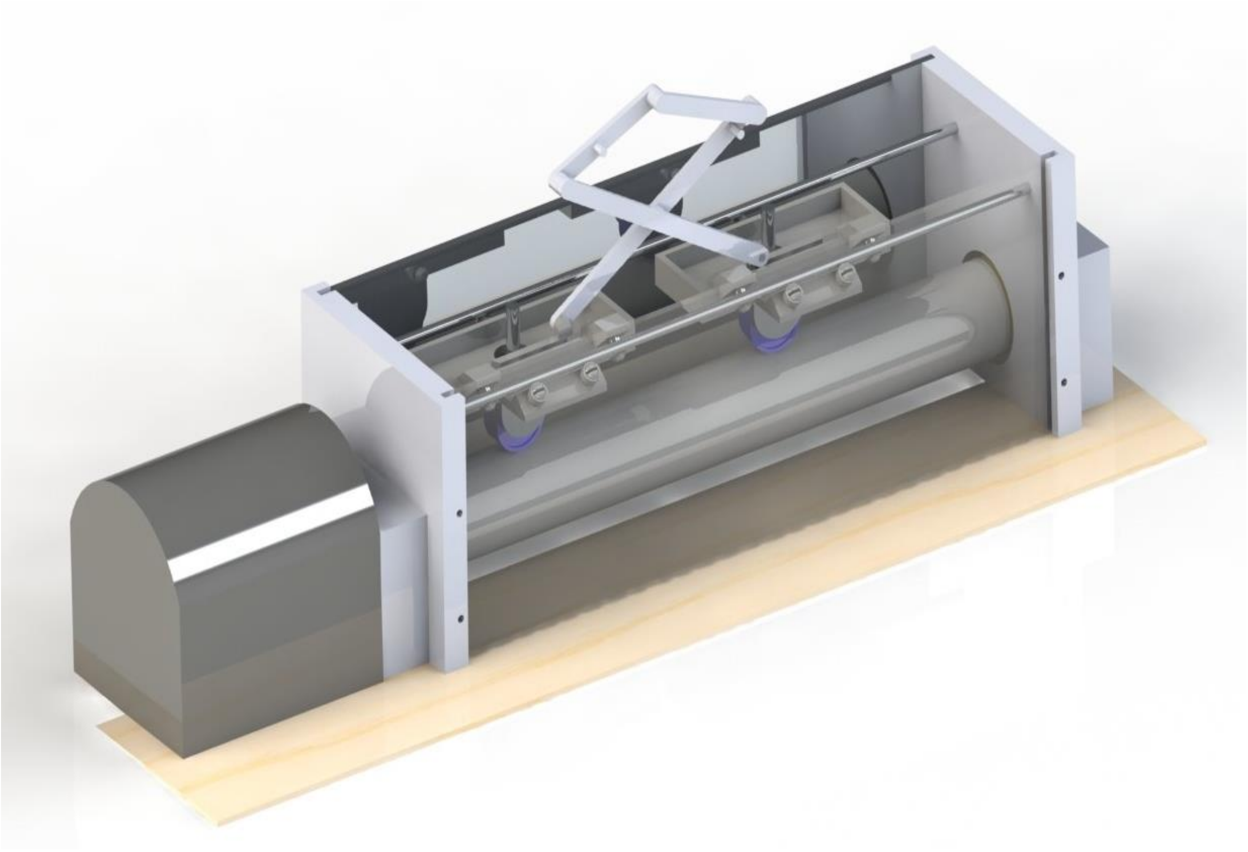
Proposed Concept

The proposed concept uses a CVT to create shapes traced by light



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Proposed Concept

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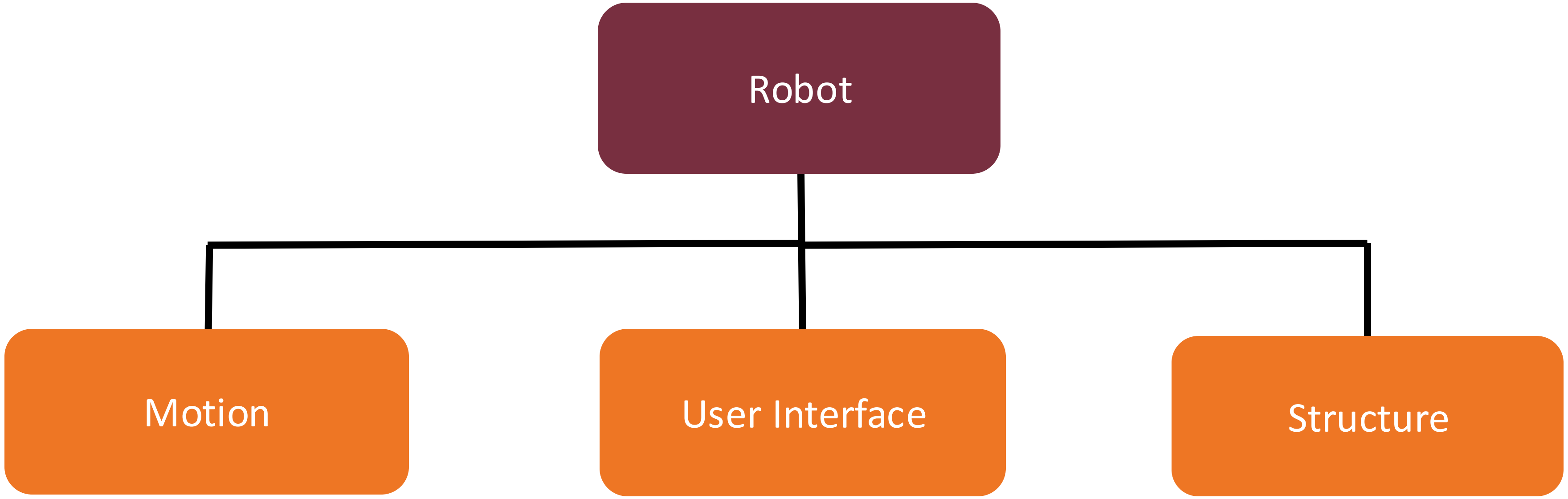
Three main systems are employed:



Cade Watson

Structure/Motion System - Update

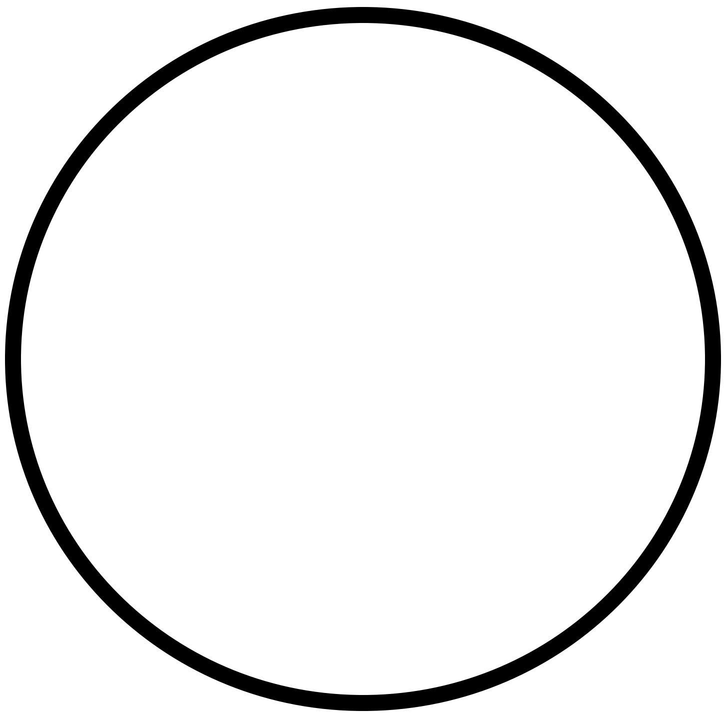
A 36” long, 3” OD, 0.049” thick Aluminum cylinder had been selected and ordered previously (along with maintenance free Bronze bushings to support rotation)

89965K421 (McMaster)

Cade Watson

Structure/Motion System – Challenges

General purpose Aluminum tubing is not made to be round



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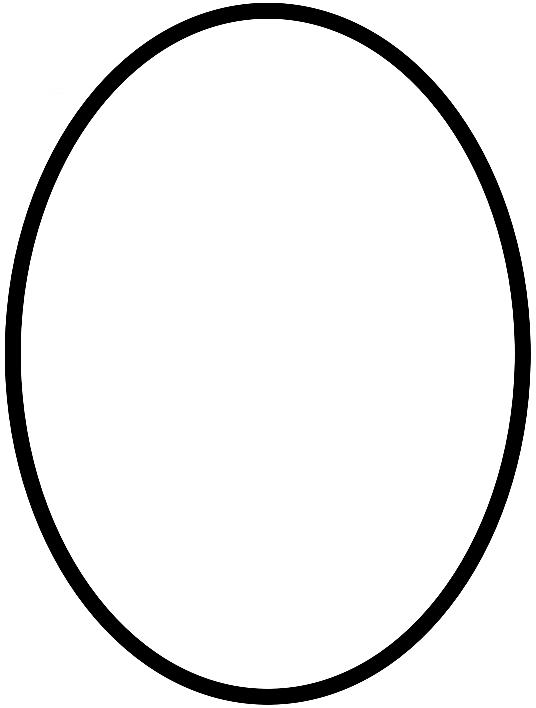
Structure/Motion System – Challenges

General purpose Aluminum tubing is not made to be round

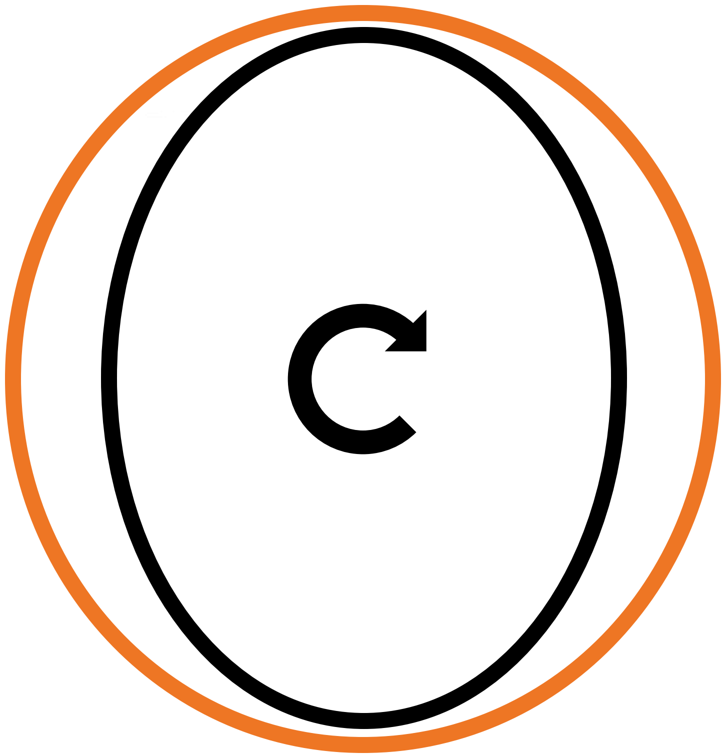


Cade Watson

Structure/Motion System – Challenges

General purpose Aluminum tubing is not made to be round

KEY:
Bronze bushing
Aluminum cylinder



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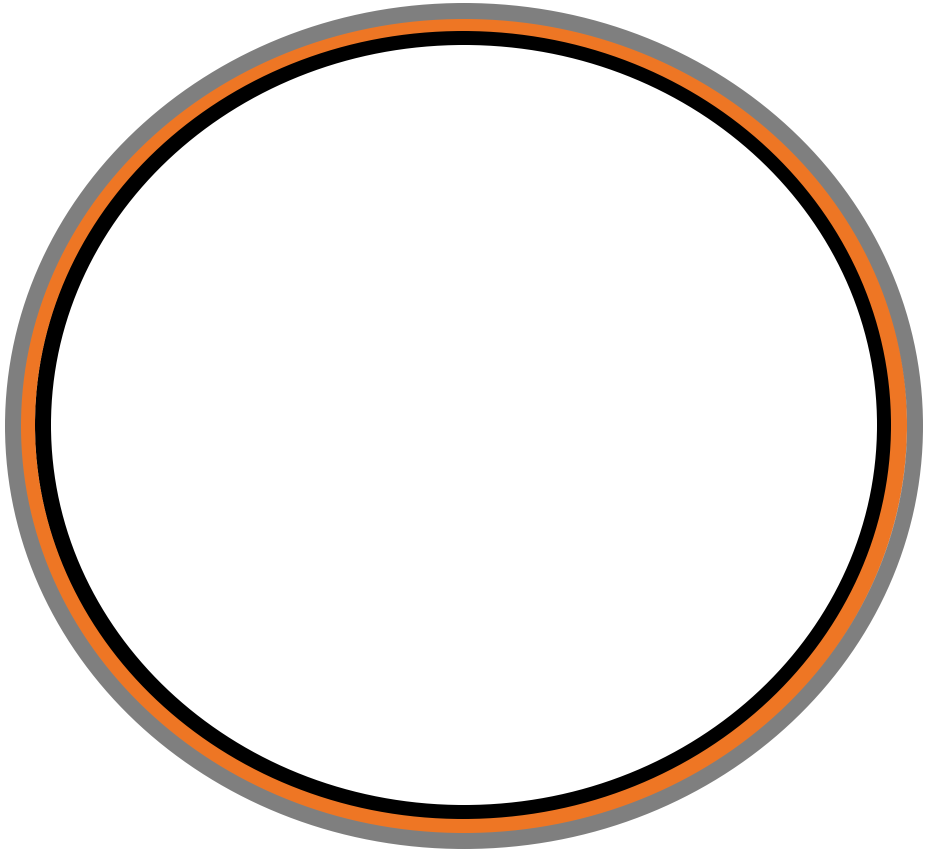
Structure/Motion System – Challenges

Solution: Press fit the very round bushings onto the cylinder and manufacture new bushings out of Delrin for the assembly to rotate in

KEY:
Delrin bushing
Bronze bushing
Aluminum cylinder



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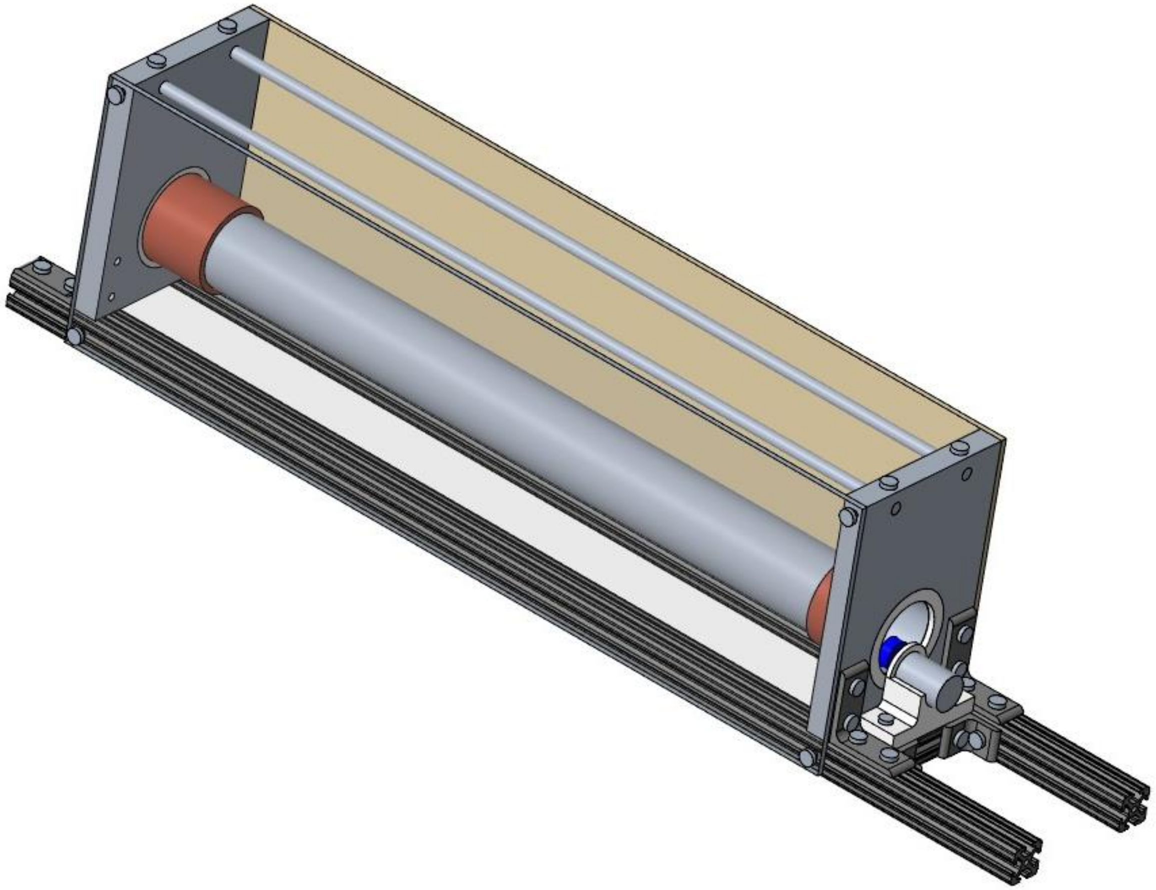
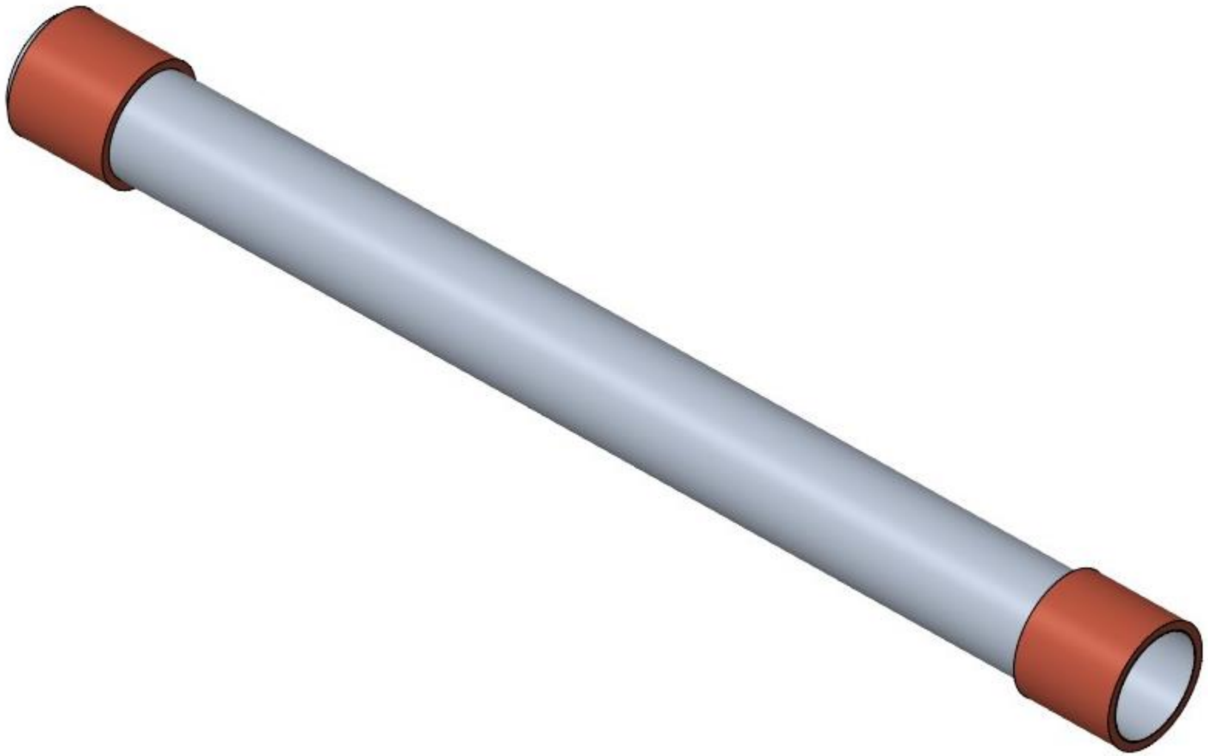
The Updated Structure Consists Of:



Cade Watson

The Updated Structure Consists Of:

Aluminum cylinder with press-fitted Bronze bushings



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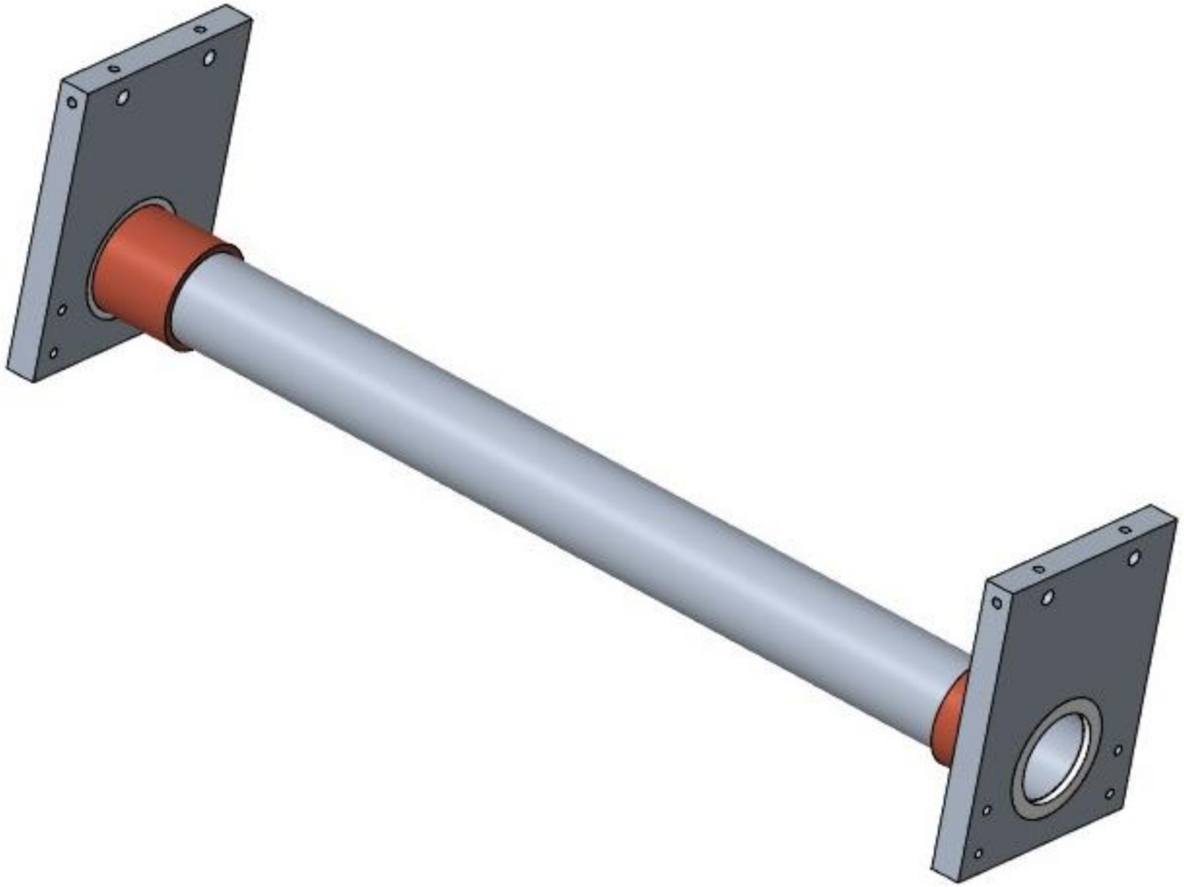
Cade Watson

The Updated Structure Consists Of:

Aluminum walls with press-fitted Delrin bushings



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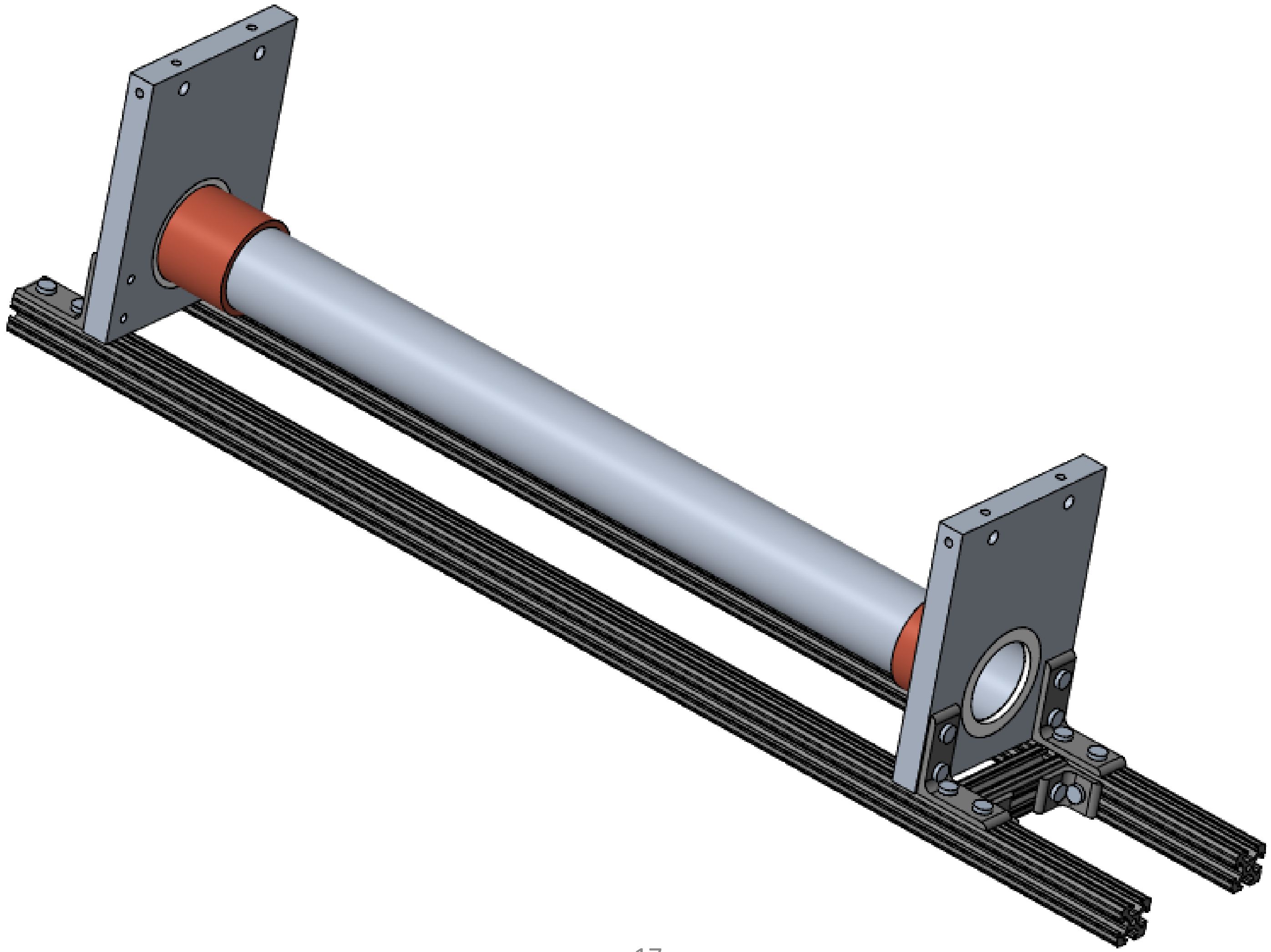
Cade Watson

The Updated Structure Consists Of:

80/20 Aluminum framing and mounting hardware



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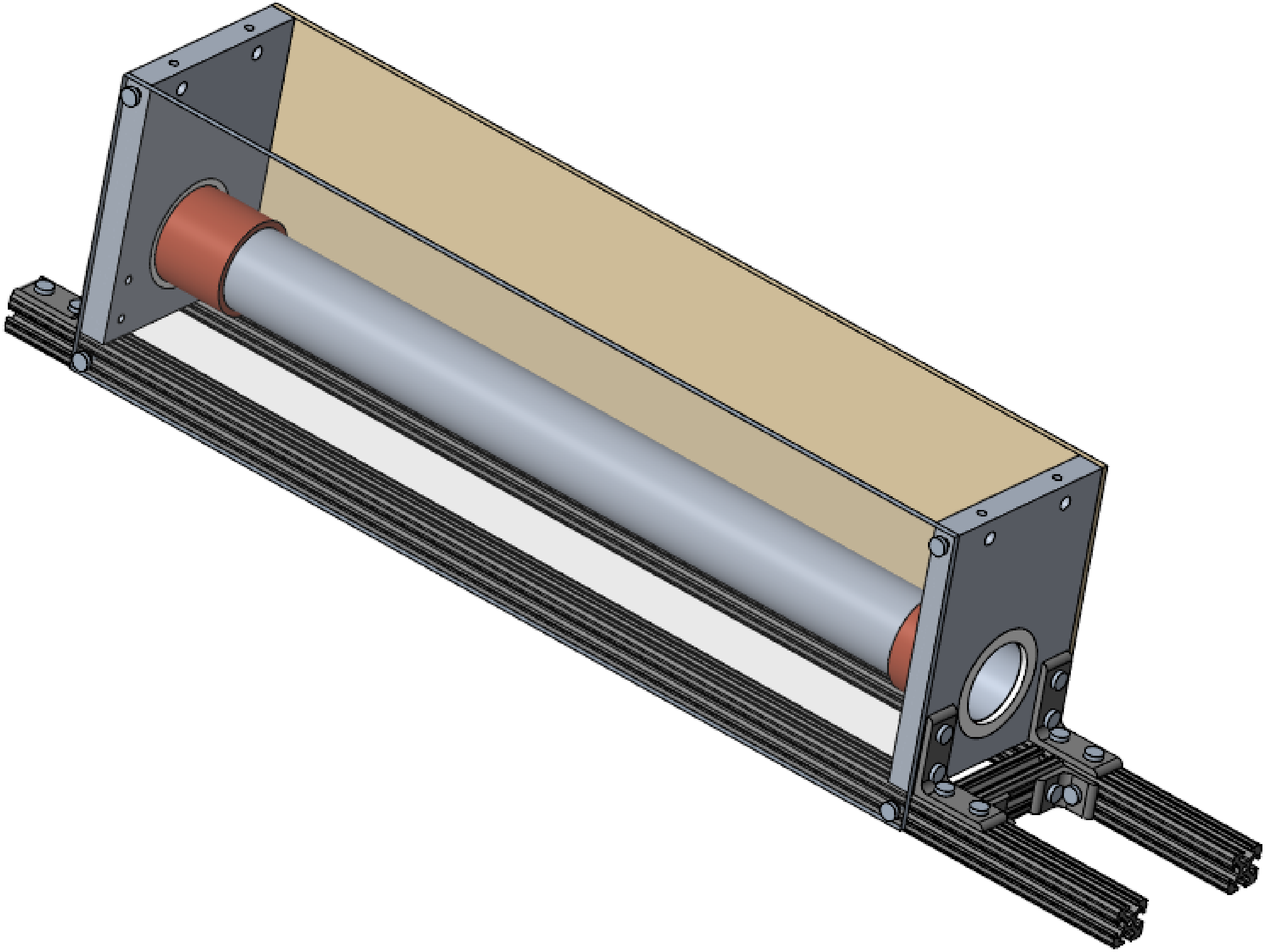
The Updated Structure Consists Of:

Side panels



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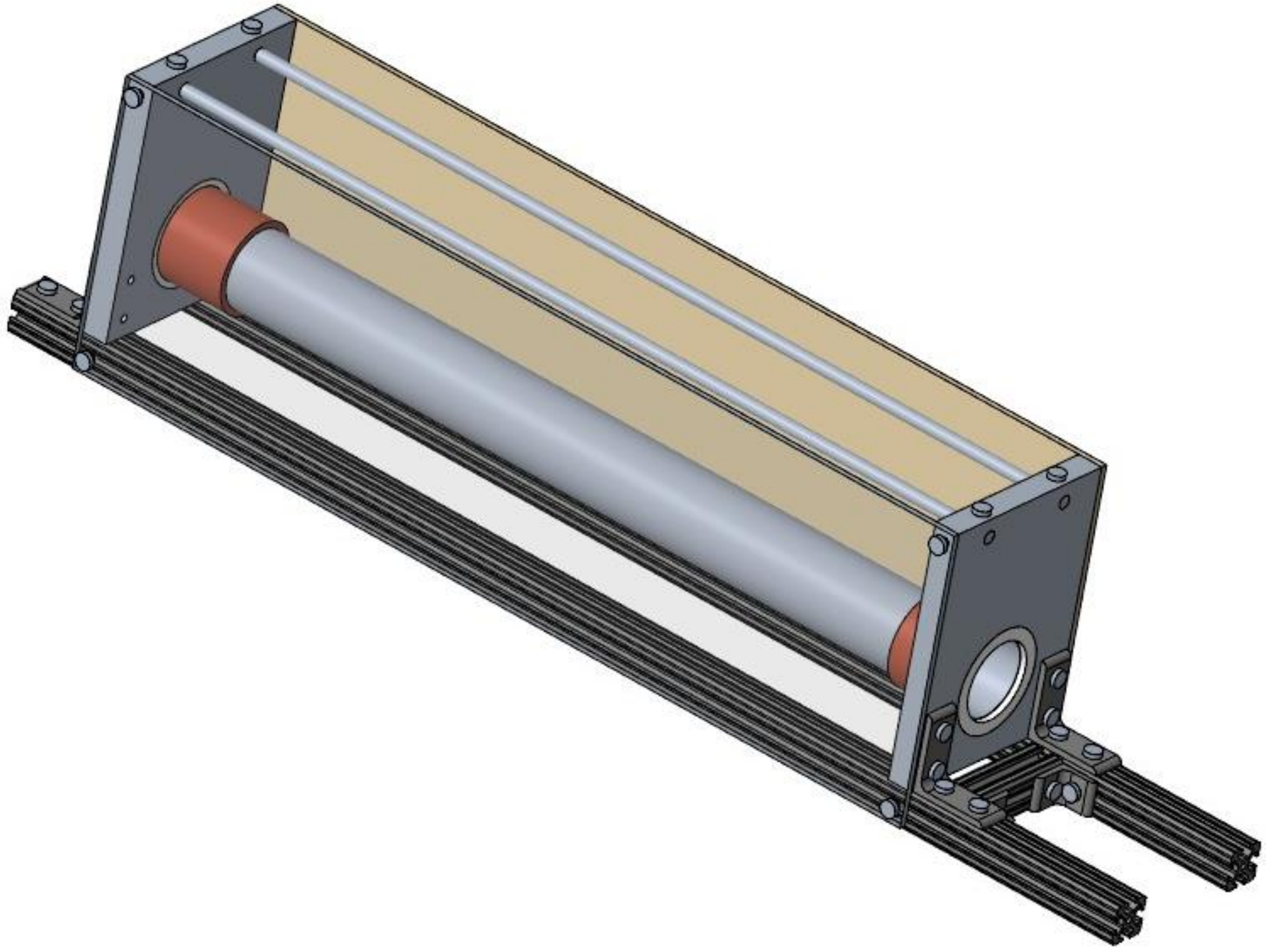
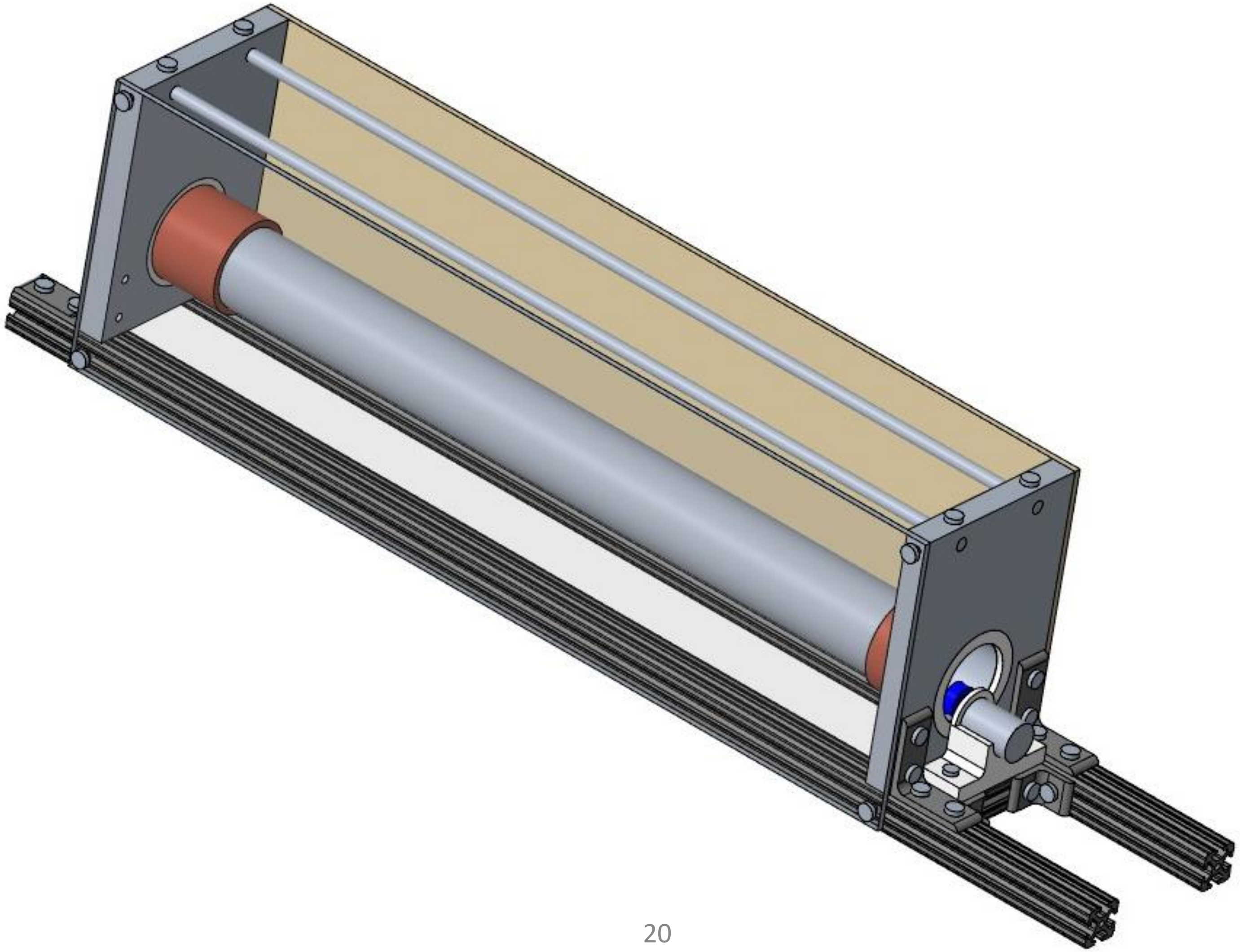
The Updated Structure Consists Of:

Carriage rails



The Updated Structure Consists Of:

Driving motor assembly



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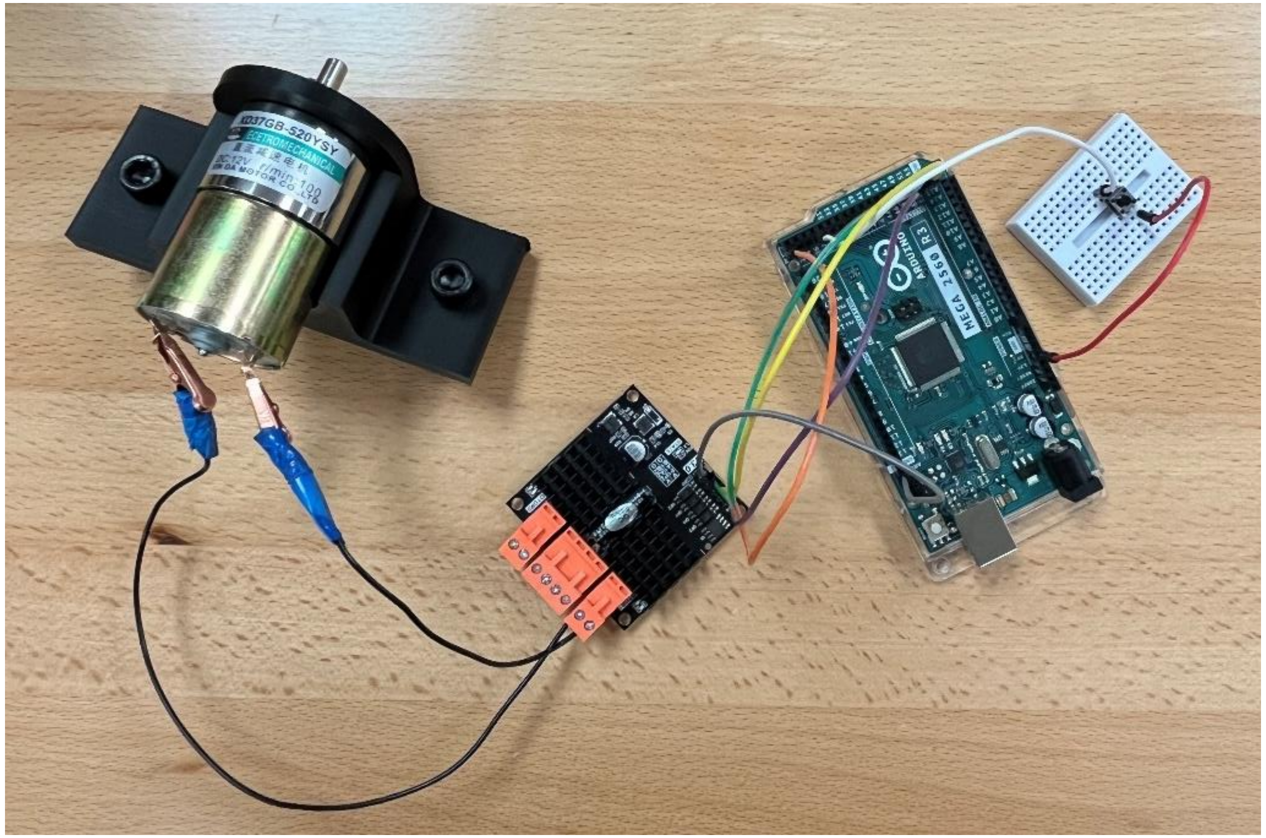
Driving Motor Assembly Wiring

- The driving motor is controlled by an h-bridge and microcontroller
- A power switch and 2A fuse will be wired in line with the 12V power input to the h-bridge



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Motion System – Wheel Update

Previously selected nylon wheels were replaced due to poor frictional characteristics

24WK28 (Grainger)

32-XGFN (AccessCasters)

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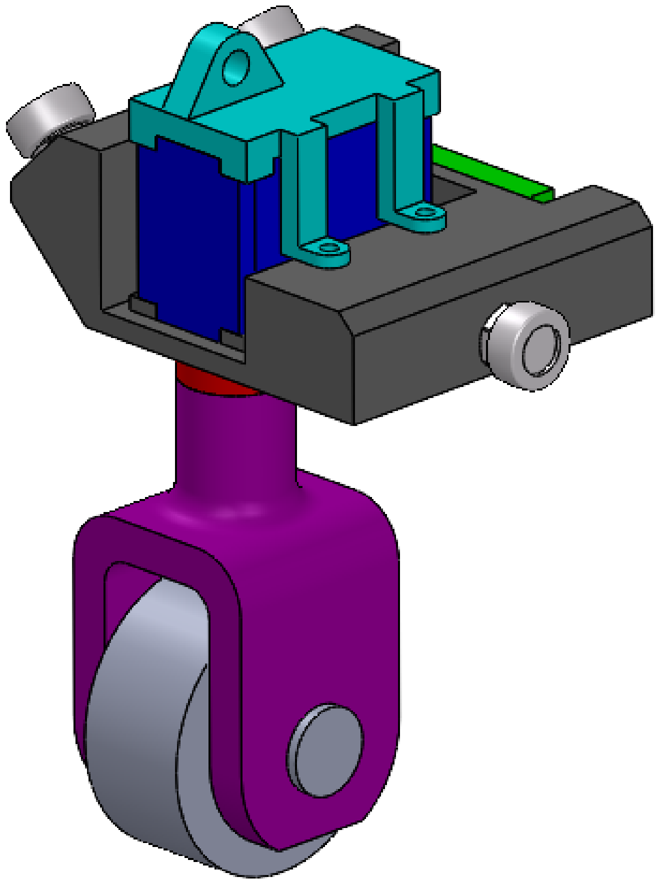
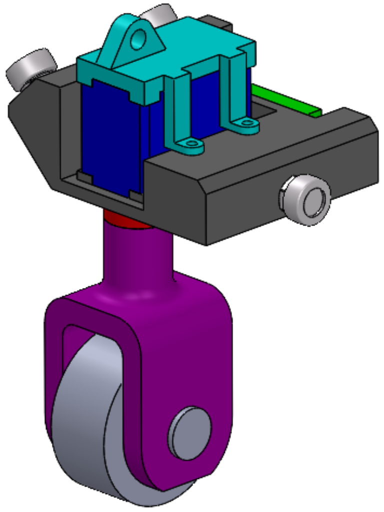
Jacob Hernandez

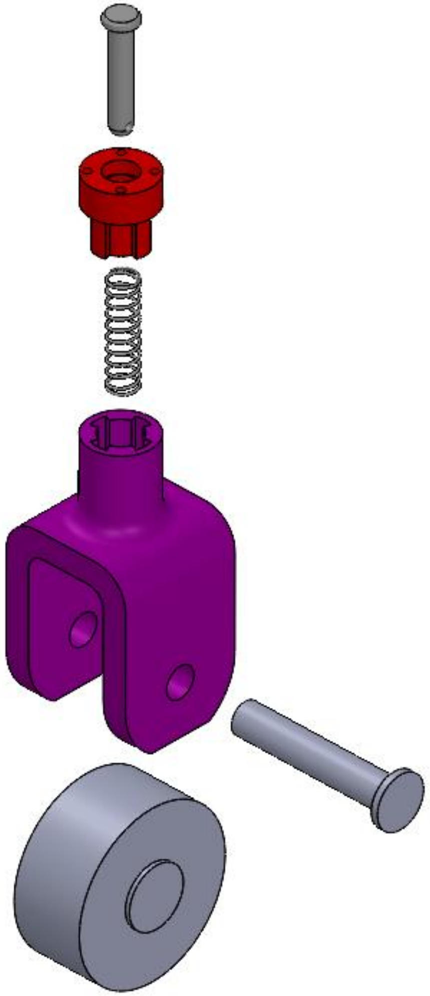
Motion System – Carriage Update



Jacob Hernandez

Carriage Update – Steering Column





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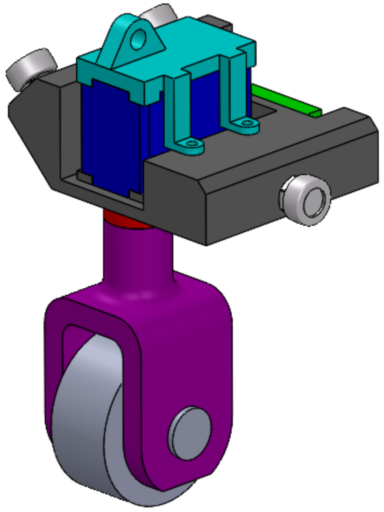
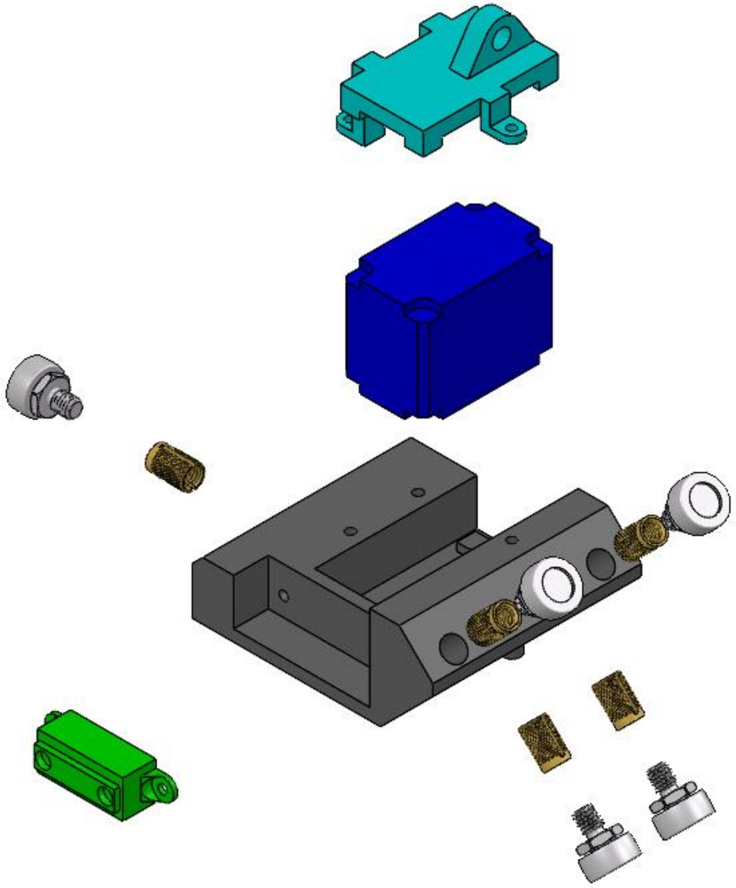
Carriage Update – Chassis





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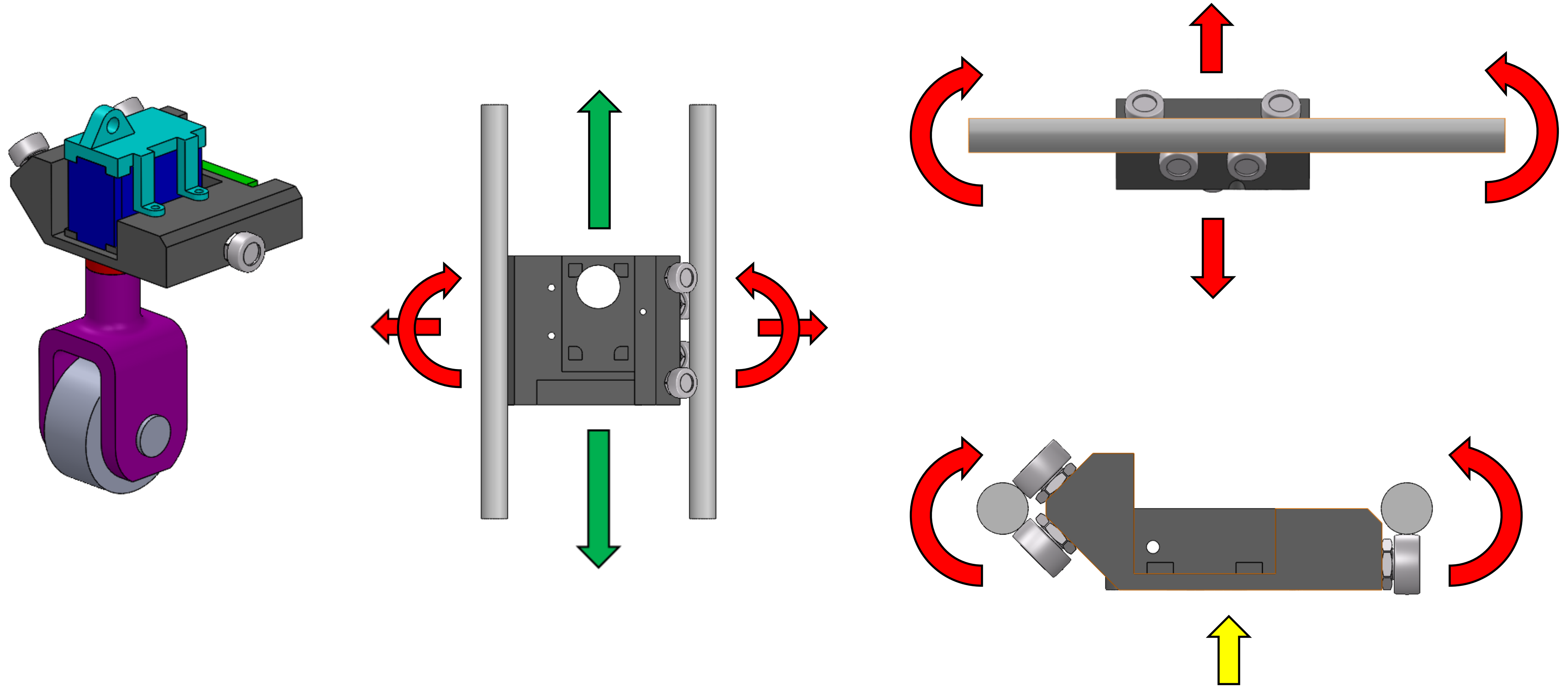
Jacob
Hernandez

Carriage Update – Roller Geometry



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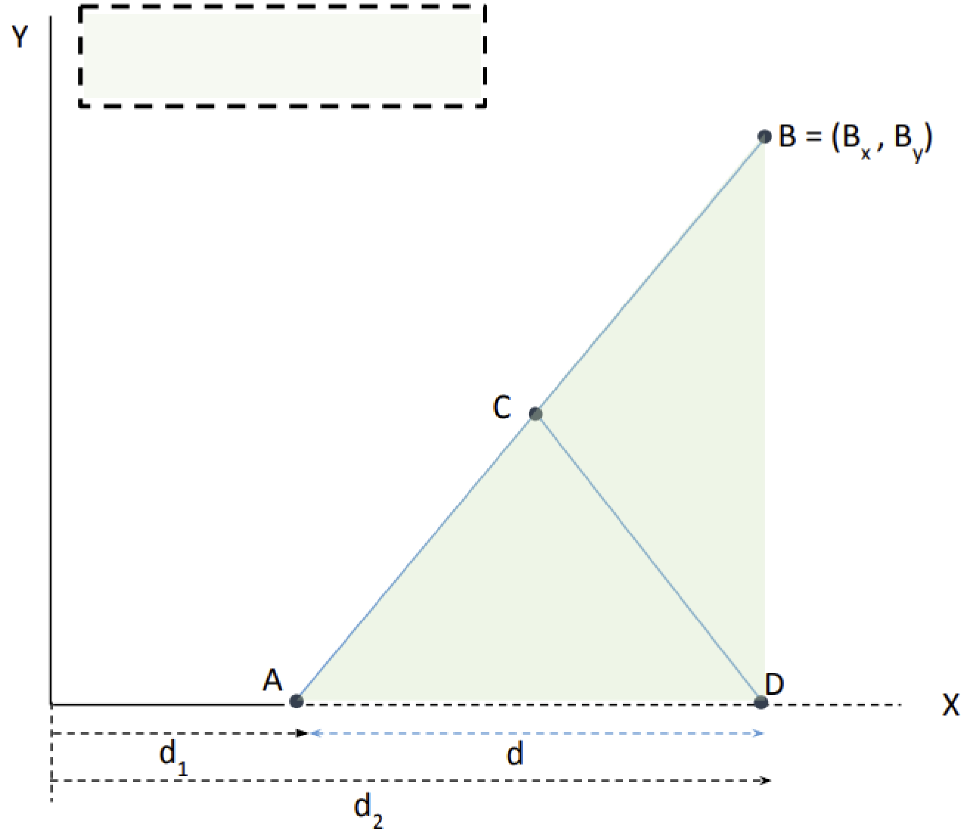
Jacob Hernandez

System Design Future Work

- Finalize motor housing design
- Finalize user console design
- Apply the electronics mapping to the physical model

Kemani Harris

Linkage Design – Prototype 0



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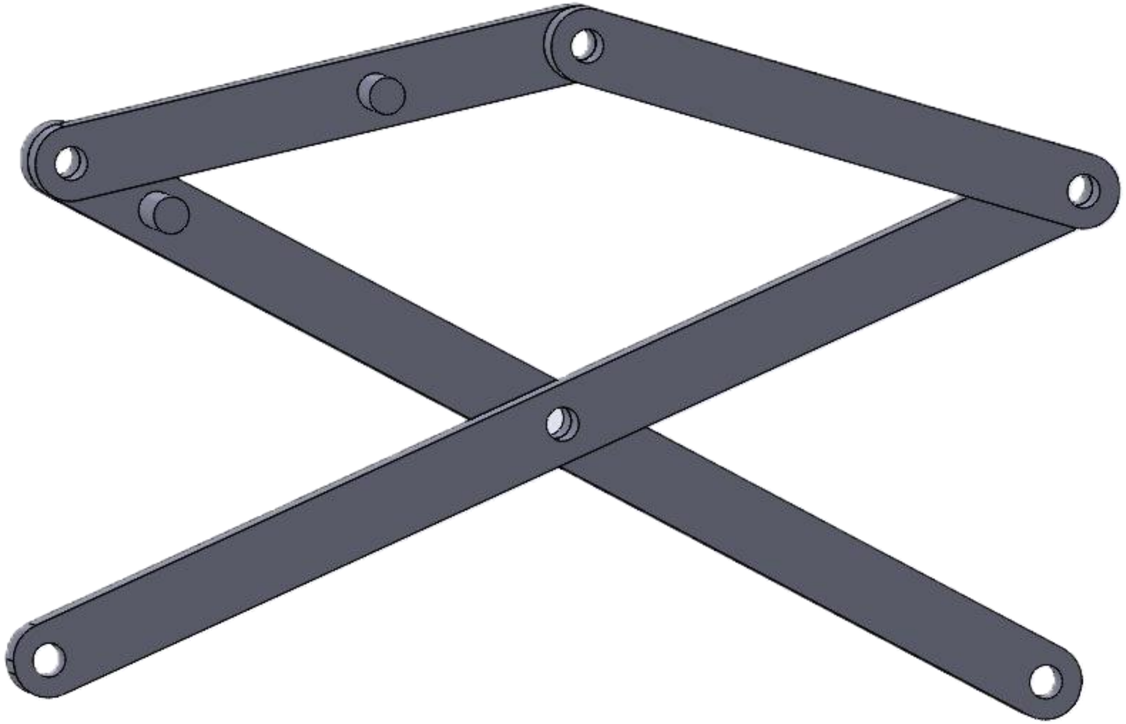
Kemani Harris

Linkage Design – New Design

- Symmetrical
- Enhances vertical motion
- Reduces horizontal displacement



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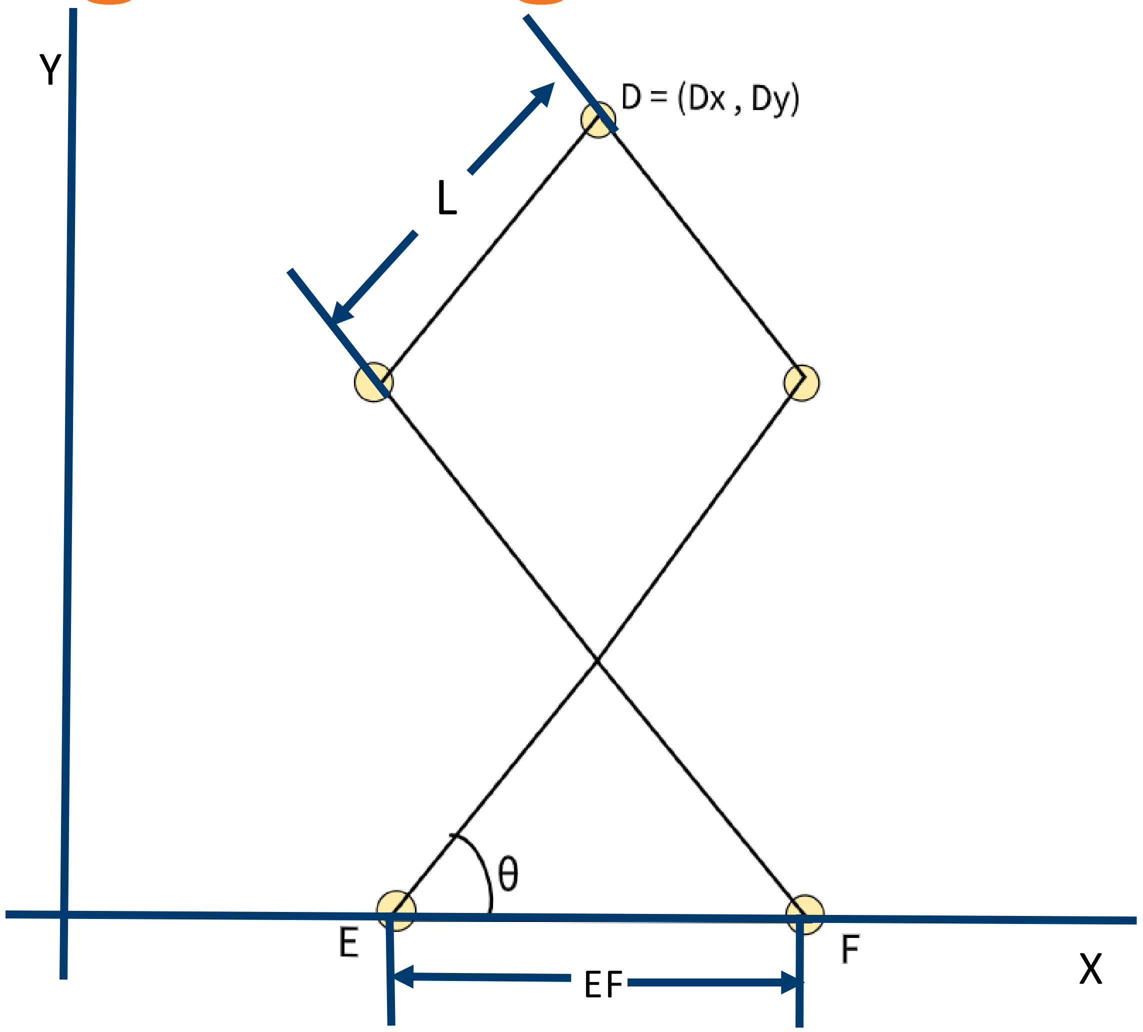
Kemani Harris

Linkage Design



L: Link Length
D: End-effector
E: Left wheel
F: Right wheel
EF: Distance between wheels

Kemani Harris

Linkage Design

Forward Kinematics

INPUT

$$E = (\Delta Ex, 0)$$
$$F = (\Delta Fx, 0)$$

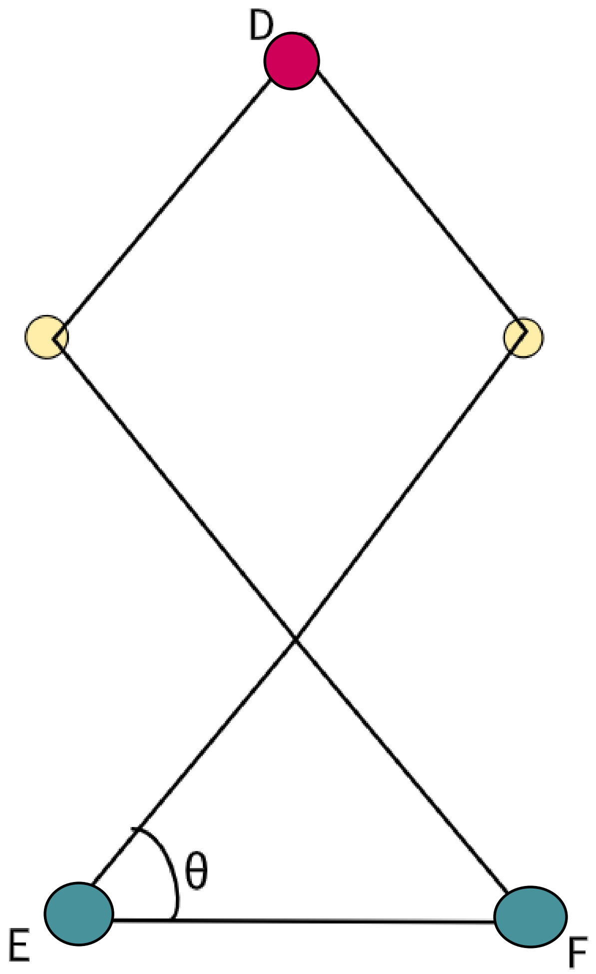
OUTPUT

$$EF = Fx - Ex$$

$$\theta = \cos^{-1}\left(\frac{L(EF)}{2}\right)$$

$$Dx = \frac{Ex + Fx}{2}$$

$$Dy = 3L\sin(\theta)$$



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Kemani Harris

Linkage Design

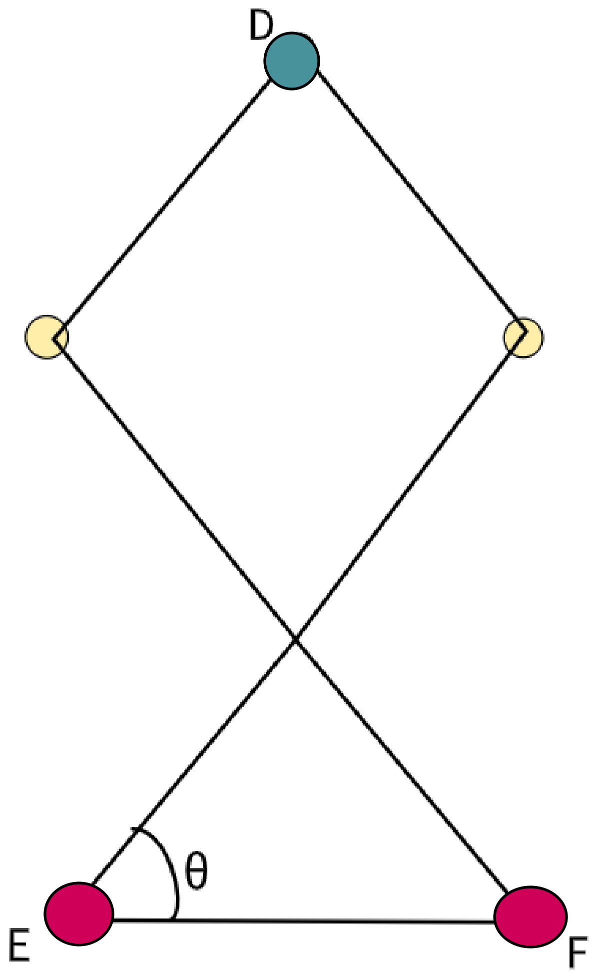
Inverse Kinematics

INPUT

$$D = (\Delta Dx, \Delta Dy)$$

OUTPUT

$$\theta = \sin^{-1}(\frac{Dy}{3L})$$
$$EF = Lcos(\theta)$$
$$Ex = Dx - EF$$
$$Fx = Dx + EF$$



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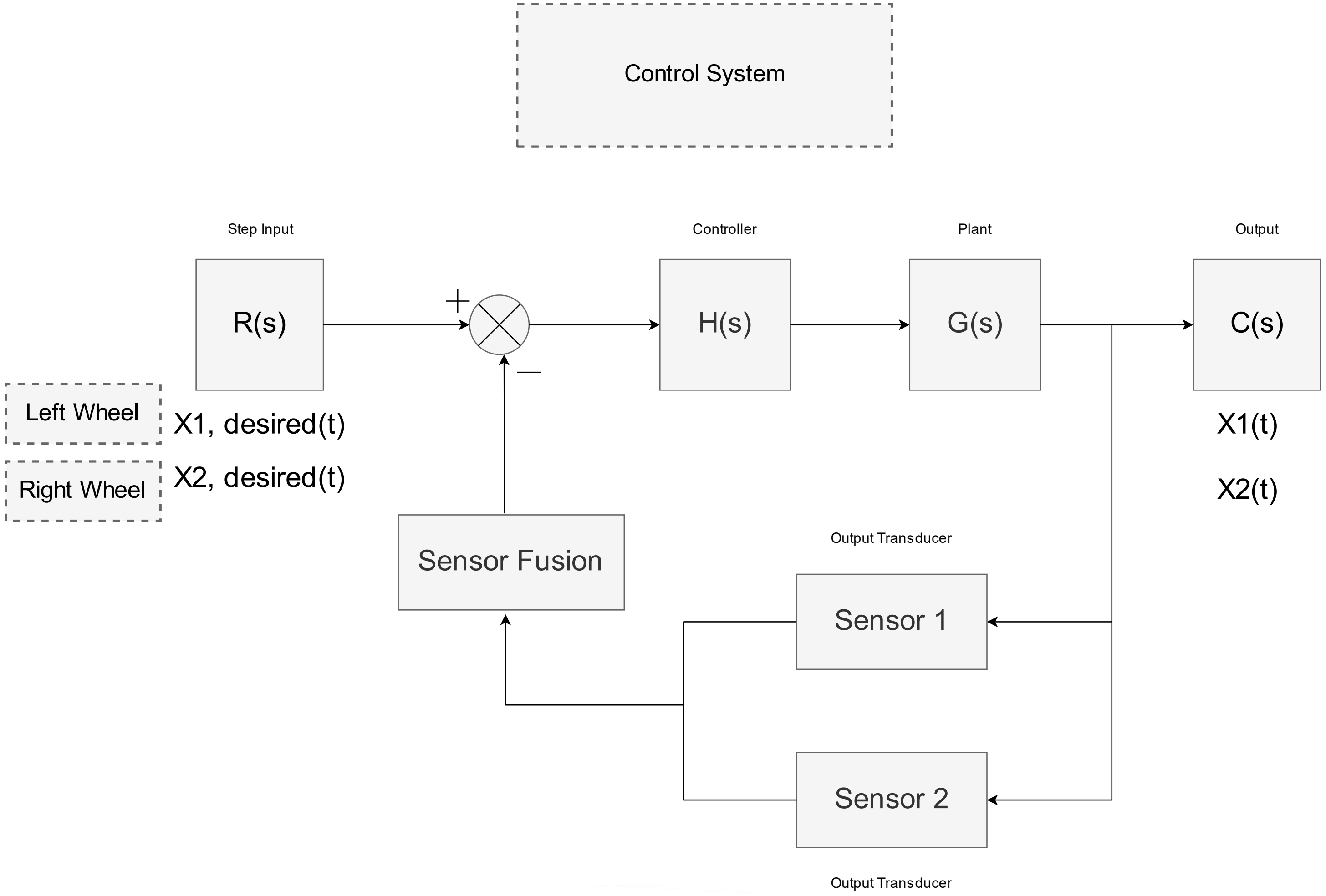
Control System Structure



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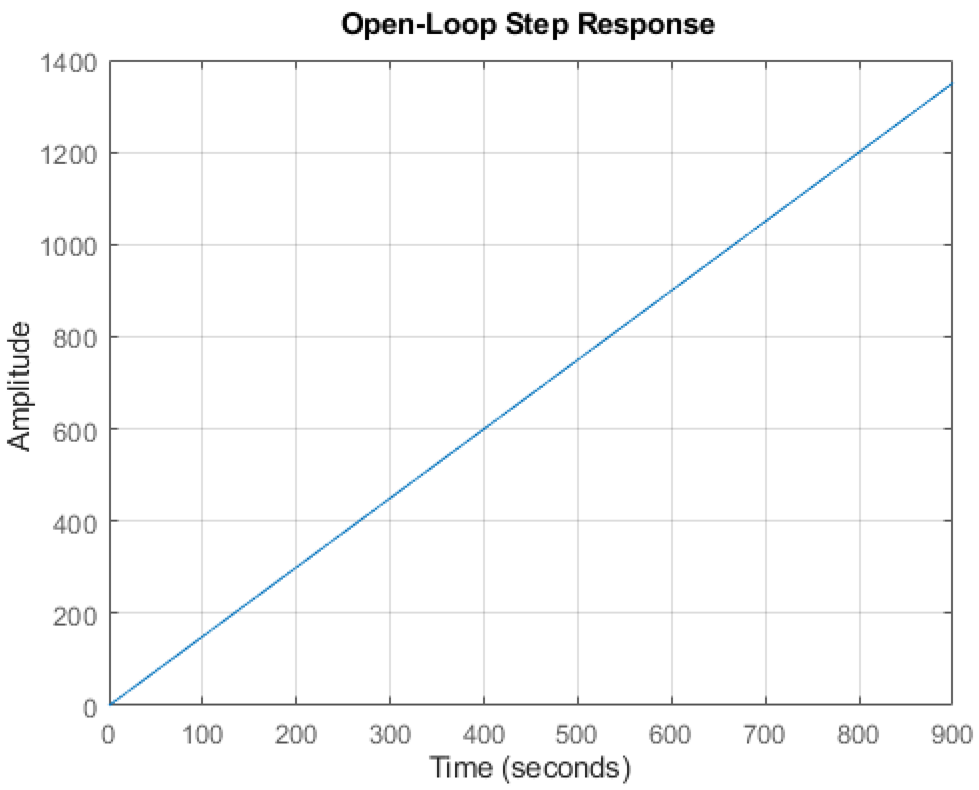
Need For Control



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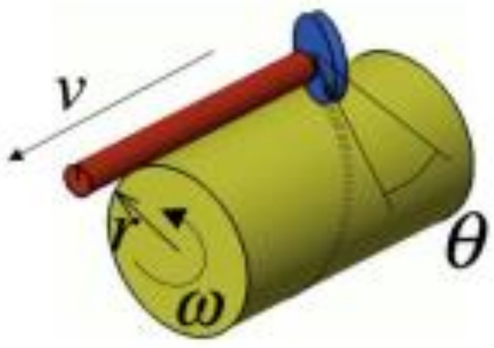
Controller Derivation



$v = r\omega \tan\theta$

$$Control\ input\ u(t) = tan\theta$$

$$u(t) = Ke(t)$$

$$tan\theta(t) = K(x_{1,desired}(t) - x_1(t))$$

$$\theta(t) = \mathrm{atan}(K\left(x_{1,desired}(t) - x_1(t)\right))$$

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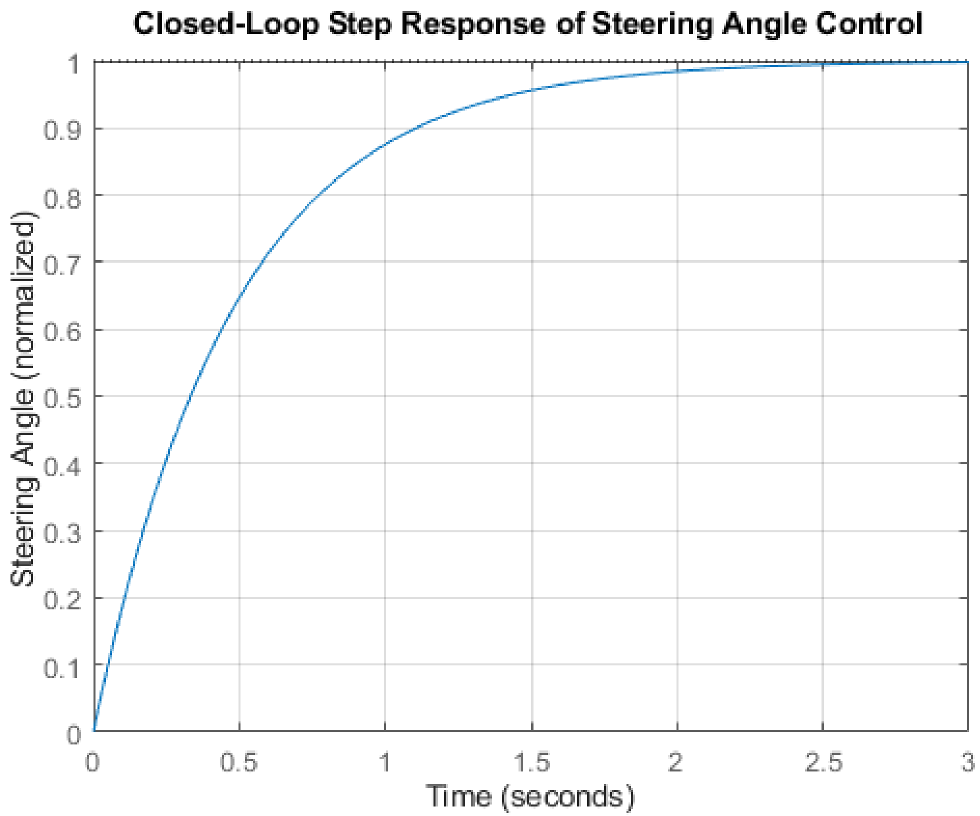
Closed-Loop Response



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Aaron Havener

Linkage Integration

- Now that desired wheel positions are a function of the linkage end-effector, the desired wheel positions can be used to draw shapes instead of being arbitrary
- How it works:
  - Once a shape is chosen, the end-effector coordinates are calculated based on the equation of the shape
  - Using the linkage's geometry, these coordinates are then used to determine the correlating desired wheel positions
  - As the wheels move to these desired positions, the current end-effector position is updated using forward kinematics

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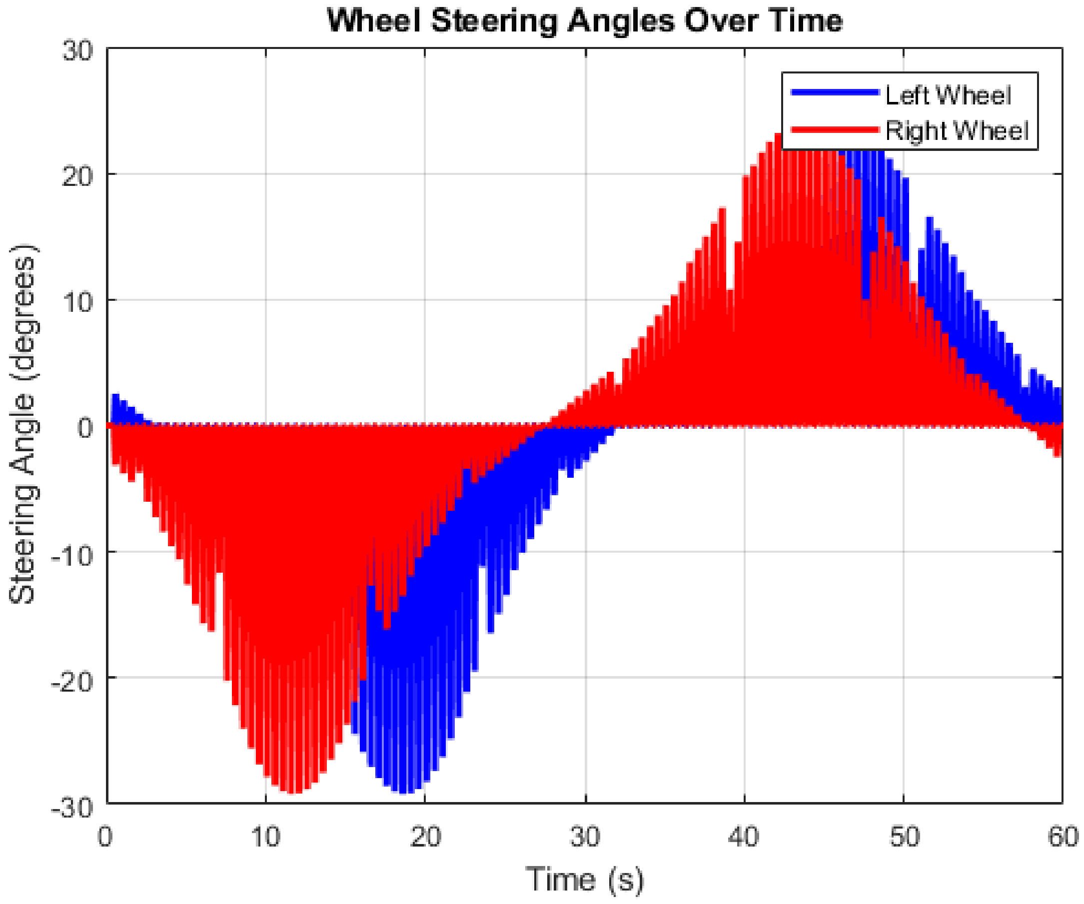
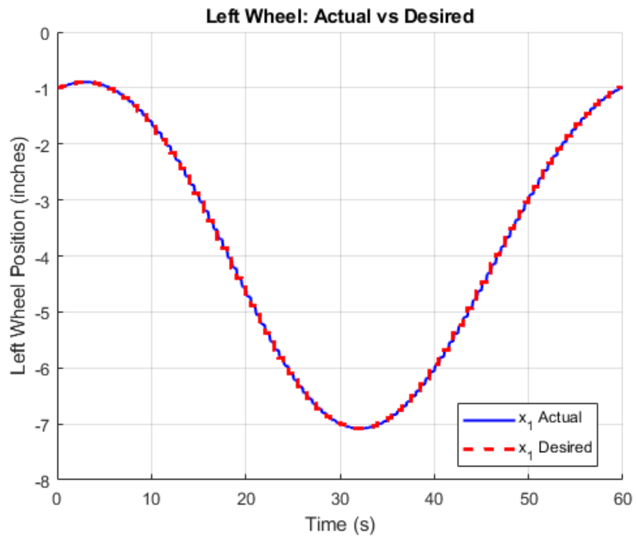
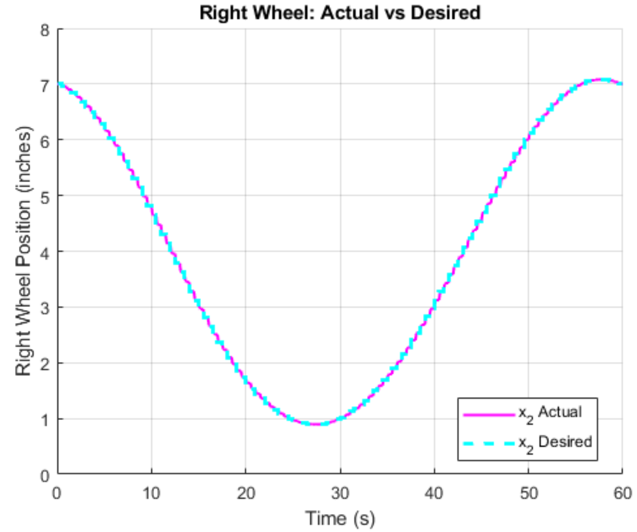
Initial Simulation Results







Aaron Havener

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Aaron Havener

Issues and Proposed Solutions

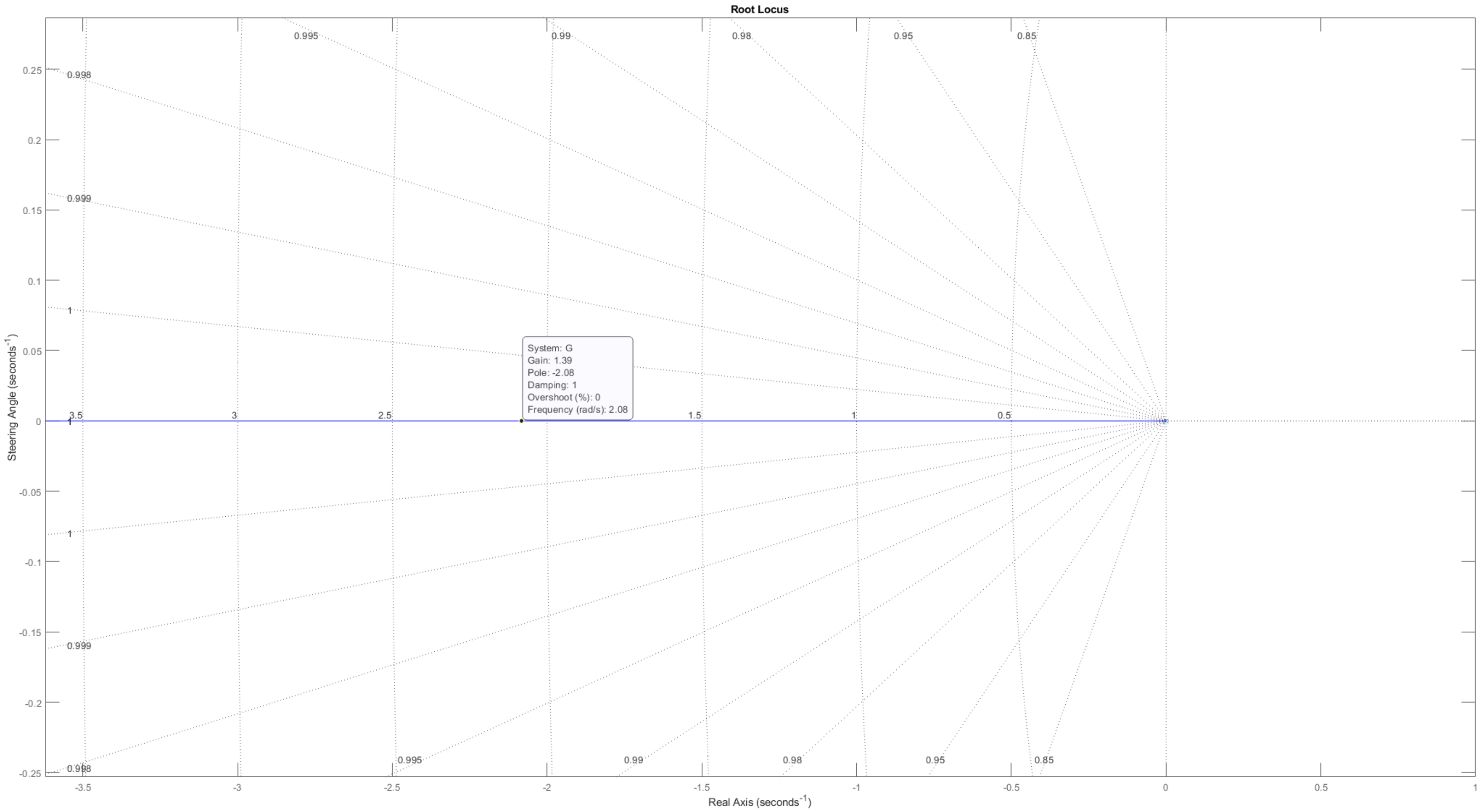
- Gain was too high and was arbitrarily approximated – needed a methodological approach
  - ➢This caused the wheels to reach the desired positions too quickly
- Resolution affected runtime – needed to be decoupled in the simulation code
  - ➢This caused timing issues, affecting the fluidity of wheel motion

Aaron Havener

Gain Determination

- Rule of thumb for cobots is to limit motion speed to 1.5 m/s
  - For safety, a maximum speed of 1 m/s was chosen. In practice, the maximum speed reached in the simulation was about 0.26 m/s
- Now that the distance (effective length of the cylinder) and the velocity are known, we can find the time constant, τ
- τ can then be used to find the pole, which in turn is used to find the suitable gain value, K

Gain Determination



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Simulation Results

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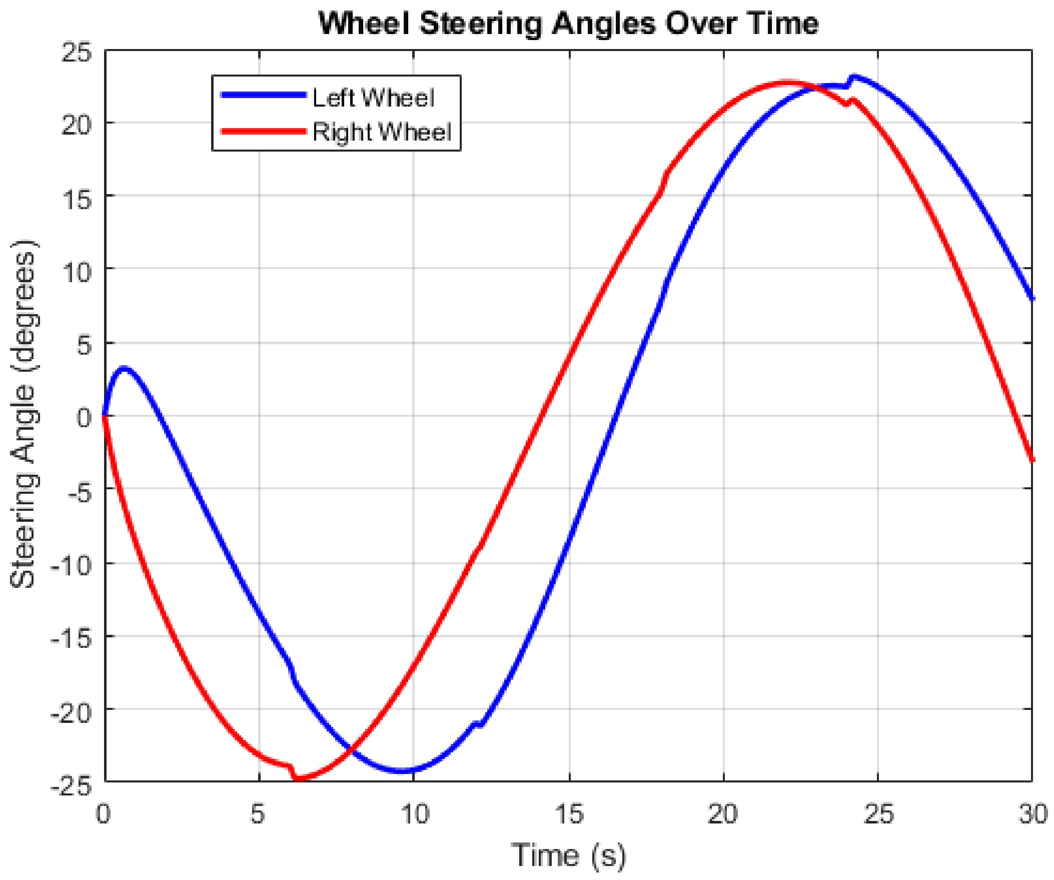

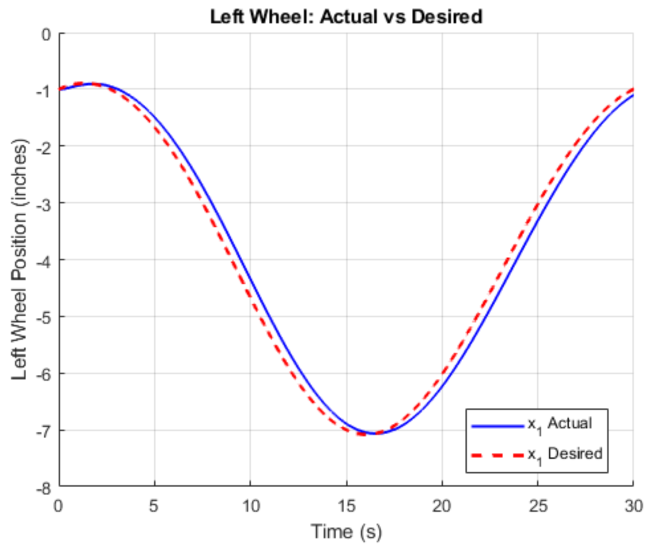

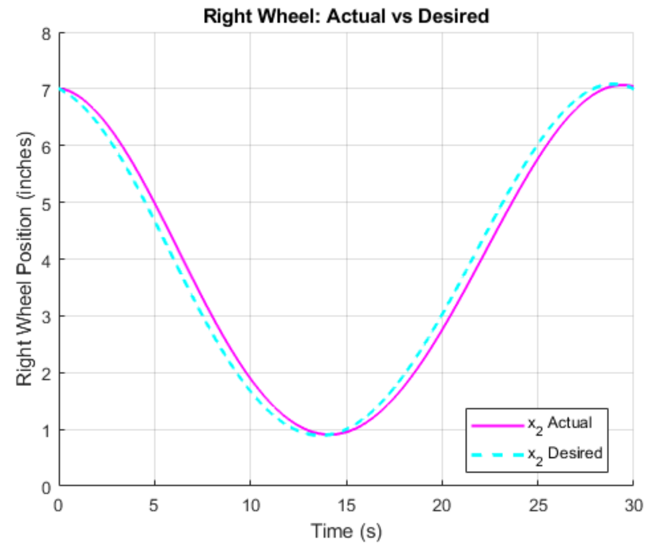

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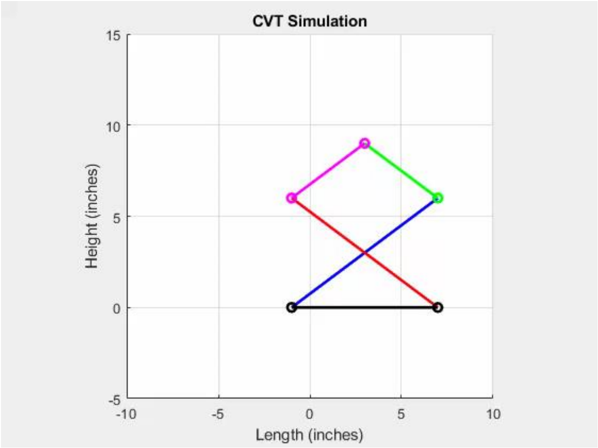
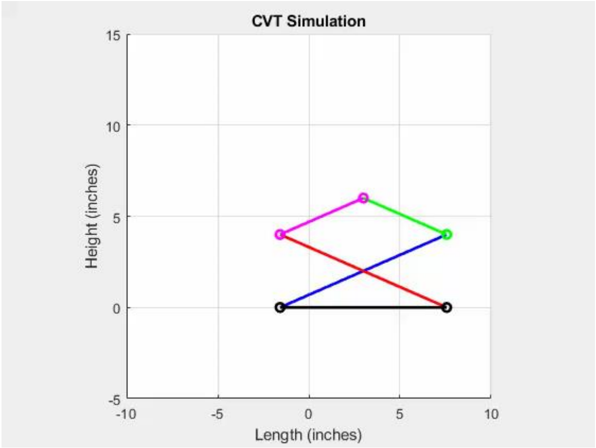
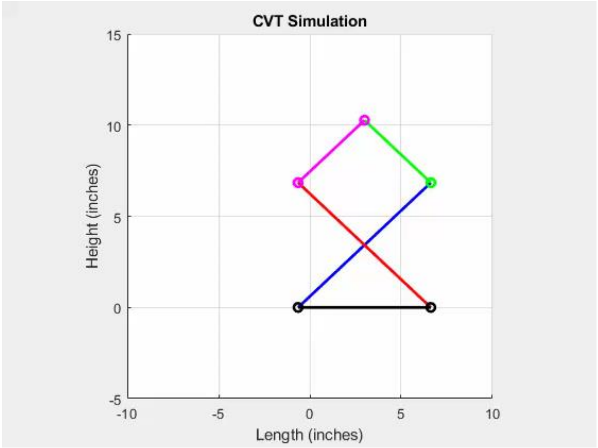
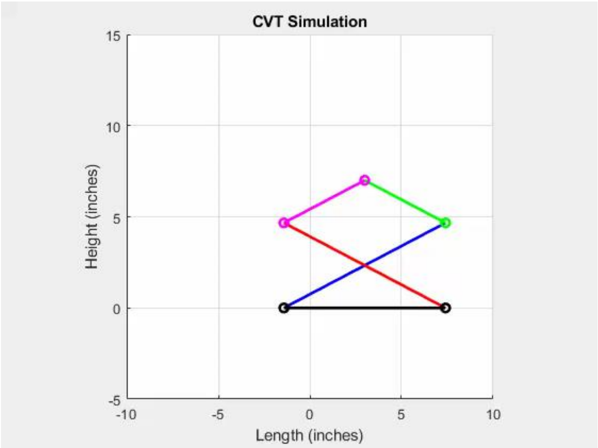
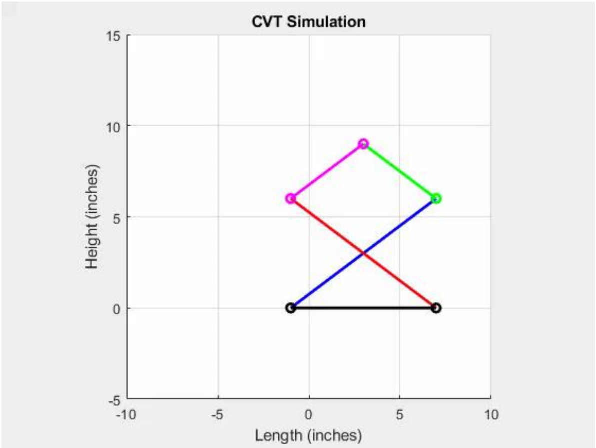
Animations

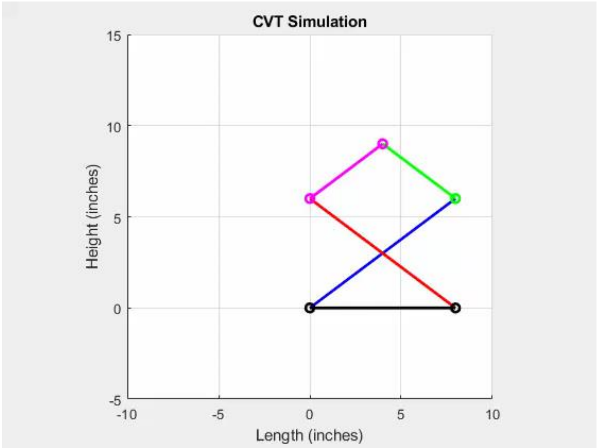












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Aaron Havener

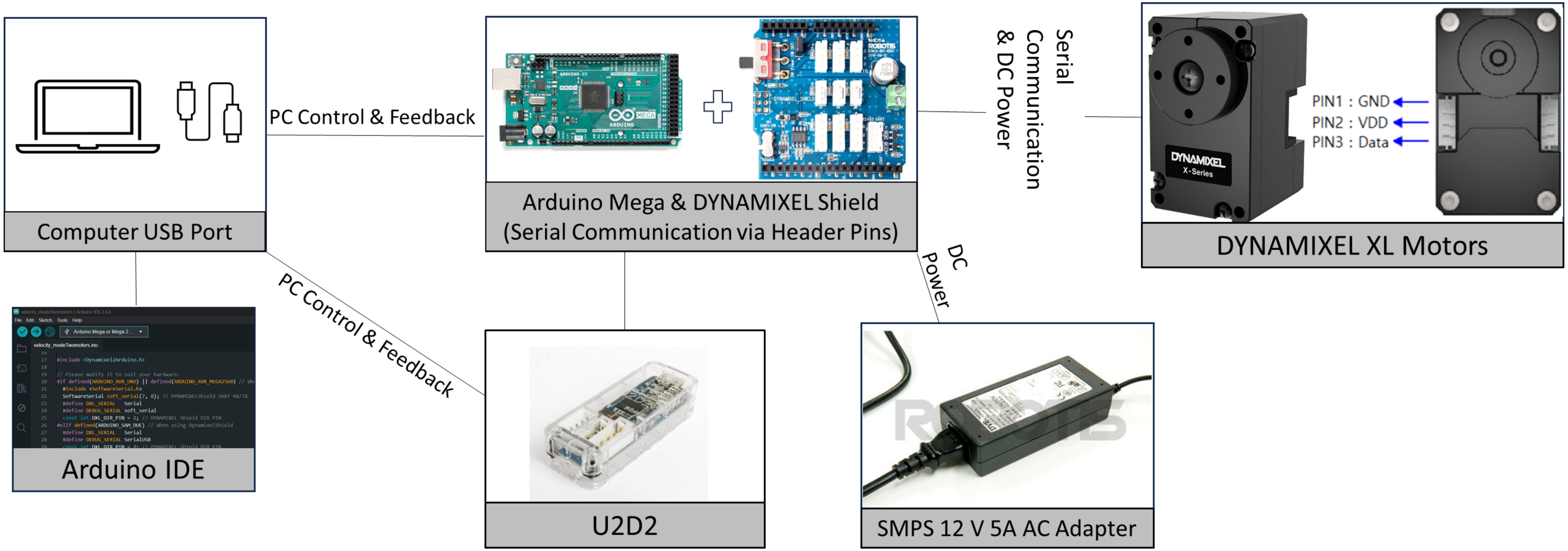
Controls Future Work

- Test on physical assembly
- Read measured data from motor encoders and infrared distance sensors as x position values for feedback
- Incorporate user interface
- Hardcode an origin or "setpoint" so errors cannot propagate between shape drawings

Aliya Hutley

Automating Motion through Smart Hardware

Steering System



- Additionally, an OLED LCD Screen and an Infrared Sensor has been selected .

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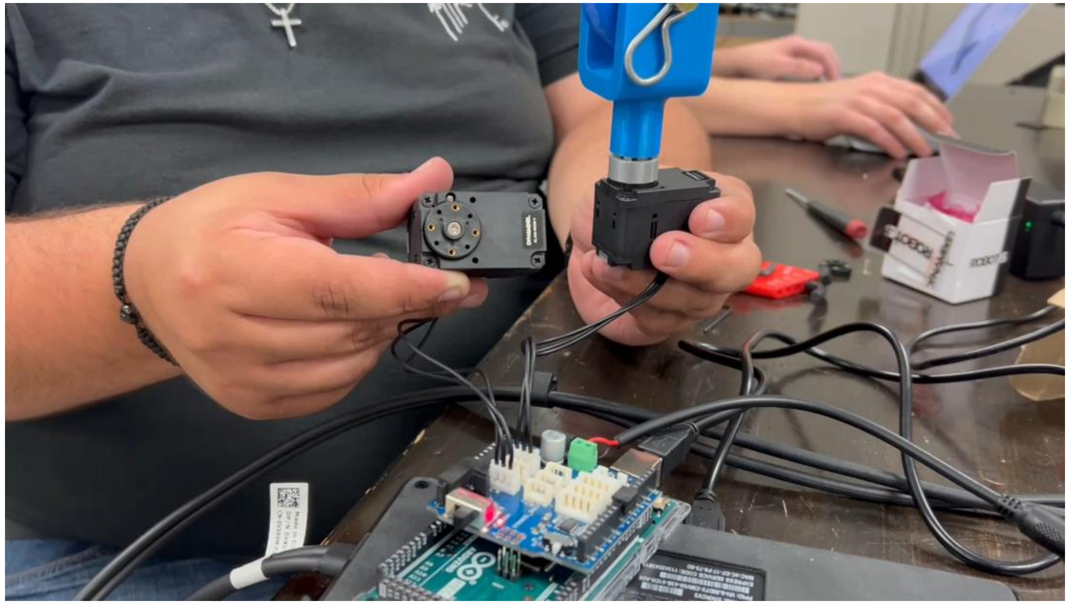
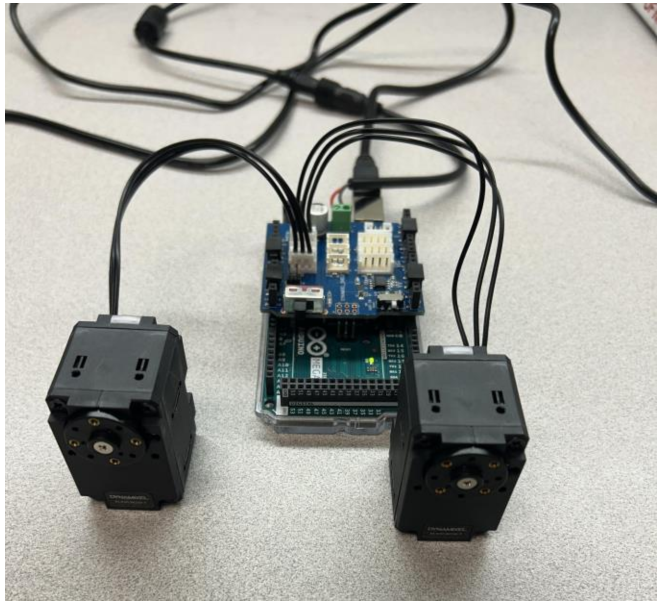
Milestone Reached: Motors Operate Independently

Aliya Hutley





- Motors were actuated and tested using the Arduino Mega 2560 and DYNAMIXEL Shield.
- Tests were performed to ensure it mated properly to the hub, carriage design and rotated as expected.
- Troubleshot power supply issues using a multimeter to measure current through individual components and isolate circuit inefficiencies.

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Future Works – What To Expect Next Time?

Aliya Hutley

Motion System:

- Simulate all electrical components at once.
- Implement motor encoders and infrared distance sensor into control feedback
- Fine tune end effector's position based on actual plotted position.

User Interface System:

- Integration with structure and motion systems
- Incorporate OLED and Laser into assembly

Structure System:

- Add safeguarding and complete assembly

Aliya Hutley

Thank You

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References

Faulring, E. L., Colgate, J. E., & Peshkin, M. A. (2006). *The cobotic hand controller: Design, control, and performance of a novel haptic display*. Department of Mechanical Engineering, Northwestern University.

Faulring, E. L., Colgate, J. E., & Peshkin, M. A. (2005). *A high performance 6-DOF haptic cobot*. Department of Mechanical Engineering, Northwestern University.

General Purpose Aluminum Tubing - 89965K421. McMaster. (n.d.). https://www.mcmaster.com/89965K421-89965K422/

APPROVED VENDOR Caster Wheel: 2 in Wheel Dia., 1 in Wheel Wd, Nylon, 550 lb Load Rating, Std. Grainger. (n.d.). https://www.grainger.com/product/Caster-Wheel-2-in-Wheel-Dia-24WK28

32-XGFN 2 inch high capacity glass filled nylon wheel. AccessCasters. (n.d.). https://www.accesscasters.com/32-xgfn-2-inch-high-capacity-glass-filled-nylon-wheel/?srsltid=AfmBOopQ_RpHfm0ysU1LeM2VaskbbDnFsNbbQUwoCRGmcKrhKl_fLYjb

Dynamixel AX-18A:ROBOTIS. (n.d.). www.robotis.us

Dynamixel AX-12A:ROBOTIS. (n.d.). www.robotis.us

Dynamixel eManual:ROBOTIS. (n.d.). www.robotis.us

https://smart-robotics.io/safe-collaboration-with-cobots/

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Back Up Slides

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Outline

- Cade – Base Design (Cylinder, supporting rotation, wheels)
- Jacob – Spring loaded hub, carriage, motor mount (Updates)
- Desired outcomes w/3d printing, prototyping, advice from technicians for changes, etc.
- Kemani – Linkage design from old to current, derivation of kinematics
- Aaron – Controls Update, animations, integration with kinematics
- Aliya – Update on Motor control, Electrical Schematic and finalized components, and converting code.

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Future Works – What To Expect Next Time?

Kinematics → Modeling & Simulation → Testing & Integration

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References

Faulring, E. L., Colgate, J. E., & Peshkin, M. A. (2006). *The cobotic hand controller: Design, control, and performance of a novel haptic display*. Department of Mechanical Engineering, Northwestern University.

Faulring, E. L., Colgate, J. E., & Peshkin, M. A. (2005). *A high performance 6-DOF haptic cobot*. Department of Mechanical Engineering, Northwestern University.

Matsushita, K., Shikanai, S., & Yokoi, H. (2009). Development of drum CVT for a wire-driven robot hand. In *Proceedings of the 2009 IEEE/RSJ International Conference on Intelligent Robots and Systems*. IEEE.

Arduino. (n.d.). Arduino Mega 2560 Rev3.

Espressif Systems. (2023). ESP32-S3 series datasheet.

Dynamixel AX-18A:ROBOTIS. (n.d.). www.robotis.us

Dynamixel AX-12A:ROBOTIS. (n.d.). www.robotis.us

TowerPro. (n.d.). *MG996R servo motor*. TorqPro. Retrieved January 17, 2025, from https://torqpro.com/product/mg996r/

PTC. (n.d.). *Friction Coefficients*. PTC Help Center. https://support.ptc.com/help/wrr/r13.0.1.0/en/index.html#page/wrr/ReferenceGuide/prediction/friction_coefficients.html

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Kemani Harris

Proposed Concept

The selected concept from Fall Semester utilizes two-dimensional motion to create an interactive guessing game using light.

Motion System – Driving Motor Selection

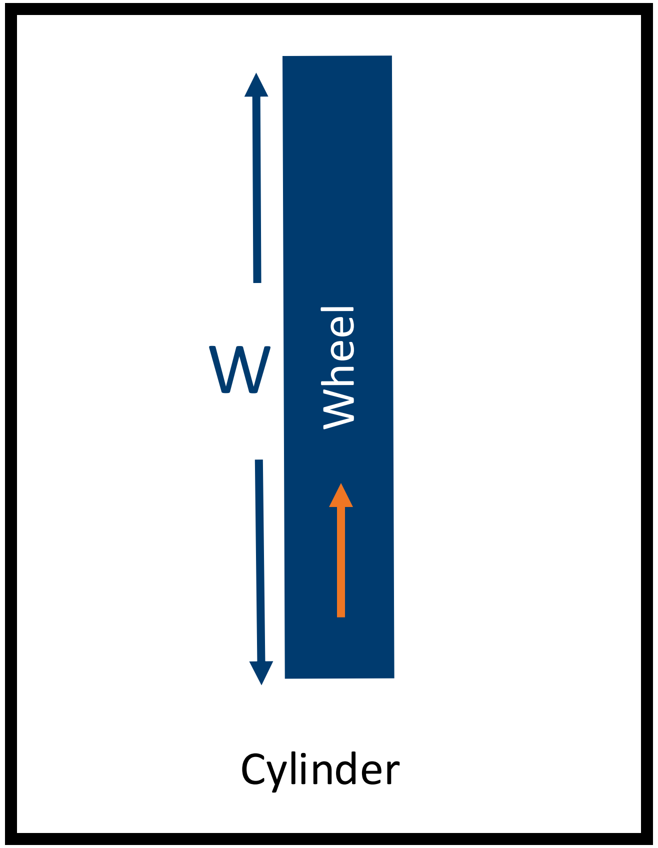
Aliya Hutley

Driving torque was calculated from frictional forces

$$\theta = 0°$$

$$F_{roll} = \frac{I_{wheel}\alpha_{wheel} + b\omega_{wheel}}{r_{wheel}} \ (small)$$

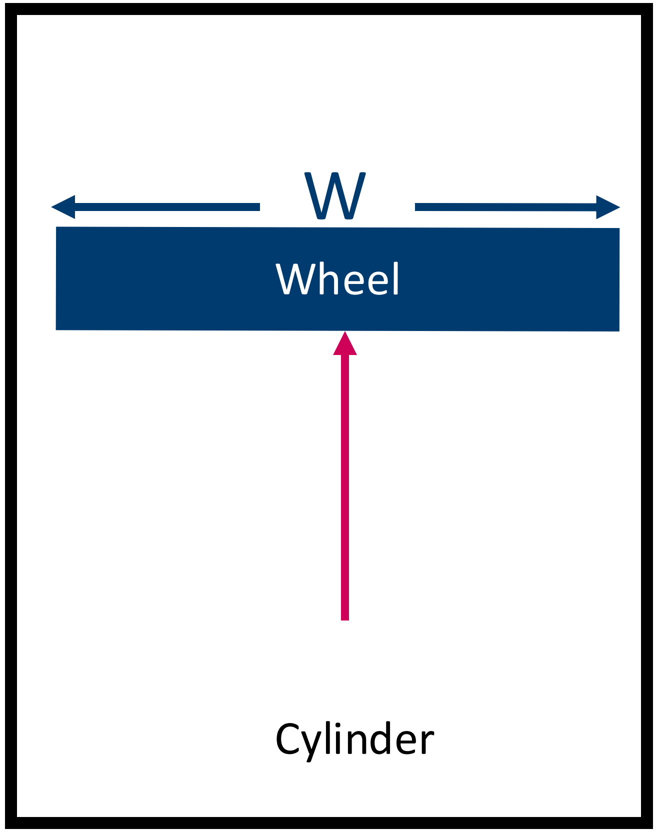
$$F_{slide} = 0$$



$$\theta = 90°$$

$$F_{roll} = 0$$

$$F_{slide} = P\mu \ \textbf{(large)}$$



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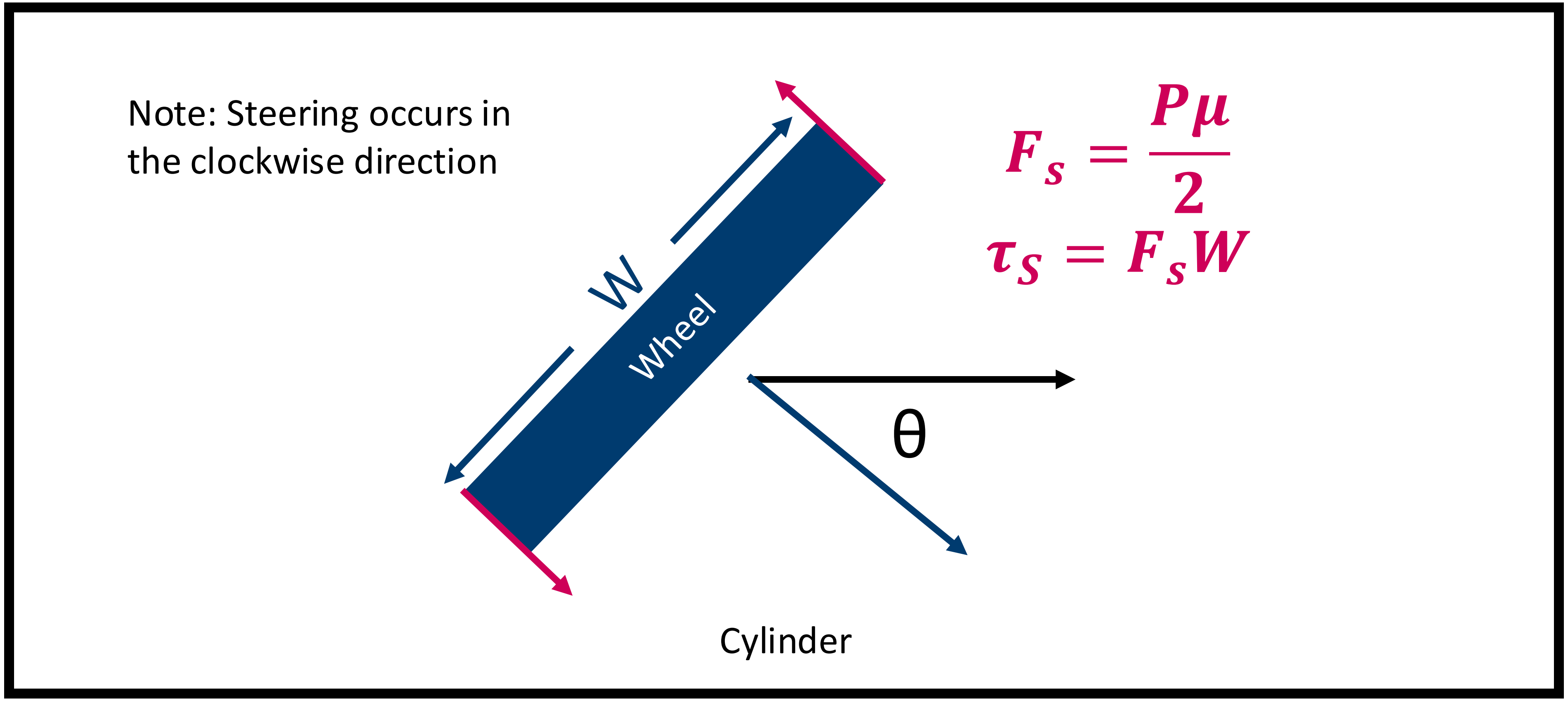
Motion System – Steering Motor Selection

Aliya Hutley

Steering motors are oversized to allow for flexibility in preload



$$F_s = \frac{P\mu}{2}$$

$$\tau_S = F_s W$$

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Motion System – Steering Motor Selection

Aliya Hutley

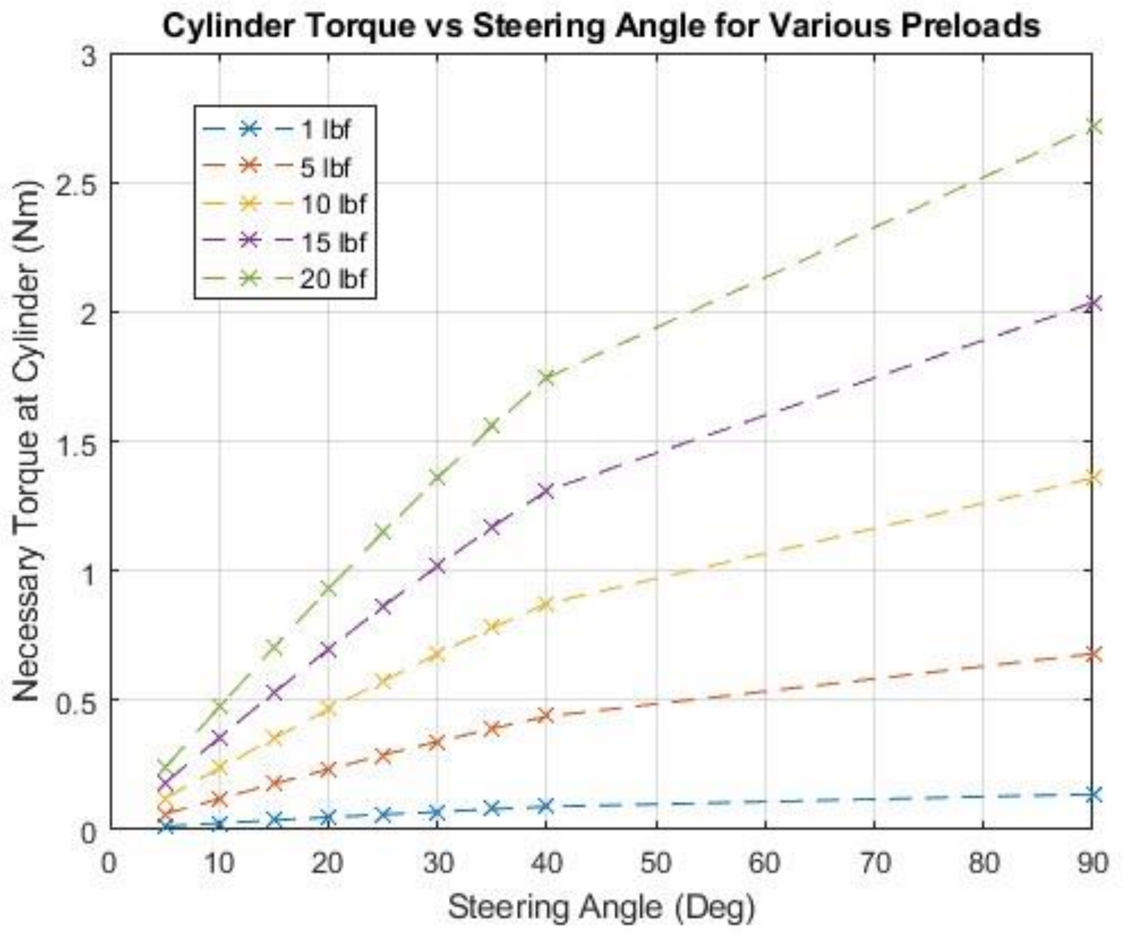
- With a maximum preload of 20 lbf, $\tau_S \approx 0.4$ Nm
- Dynamixel servo models Ax-18a and Ax-12a were compared as candidates (Ax-18a selected for higher torque and speed capabilities)

Motion System – Driving Motor Selection

Aliya Hutley

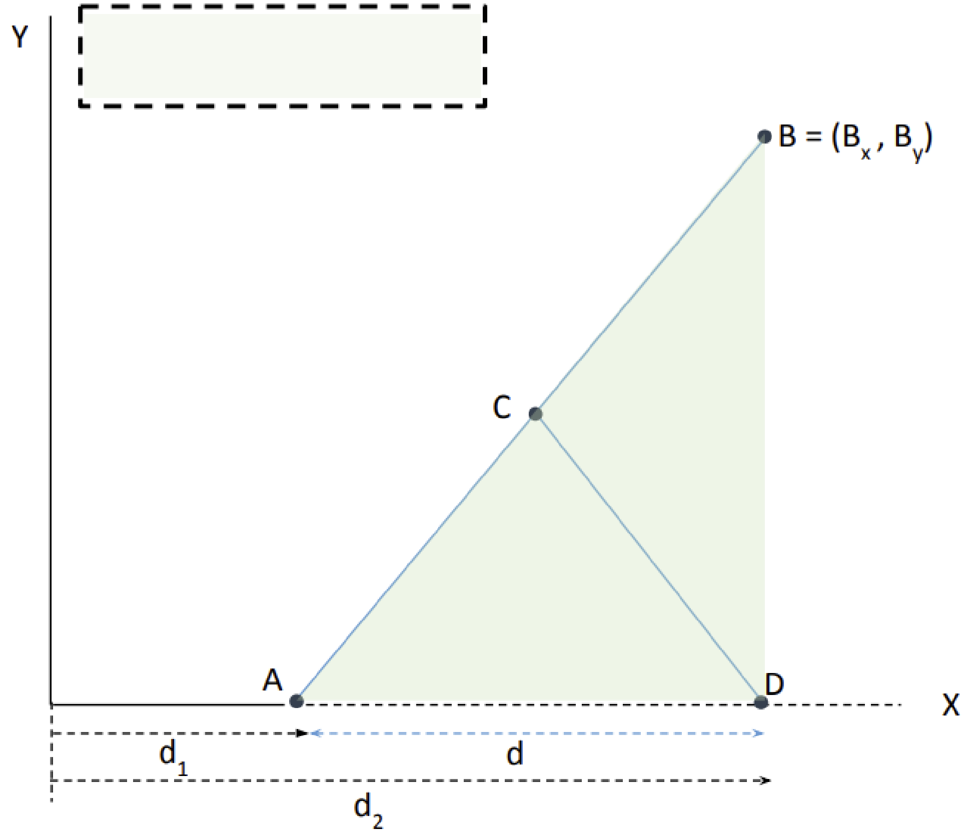
An approximation can be made for the Torque at the cylinder:

$$T_{cyl} = I_{cyl}\alpha_{cyl} + 2\mu P sin(\theta)$$



Kemani Harris

Linkage Design – Prototype 0

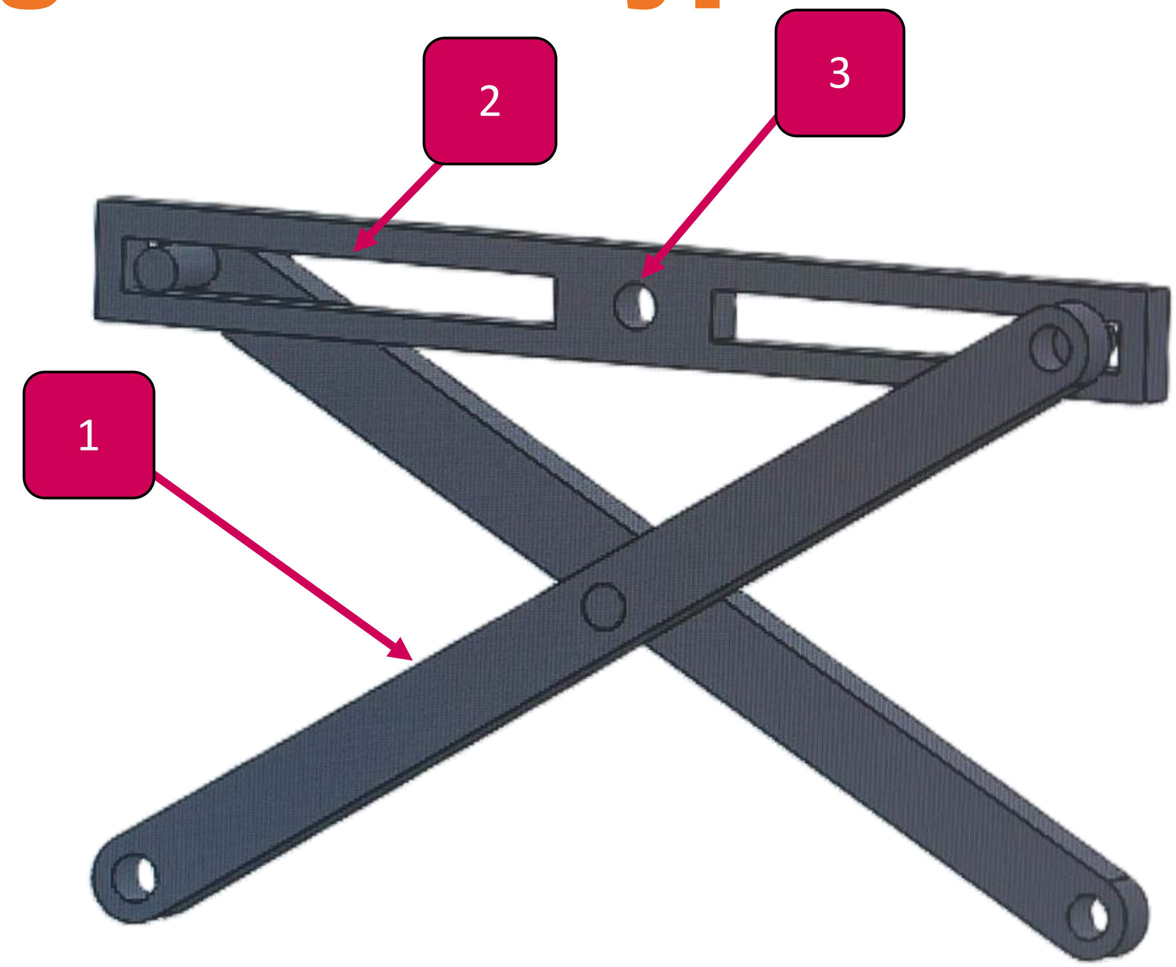


Linkage Design – Prototype 1

1) Equal Link Length

2) Slider Linkage

3) Middle Coupler Point



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Kemani Harris

Linkage Design – Prototype 1

Downside

- 3 Degrees of Freedom
- Stabilization
- Waste of Resources

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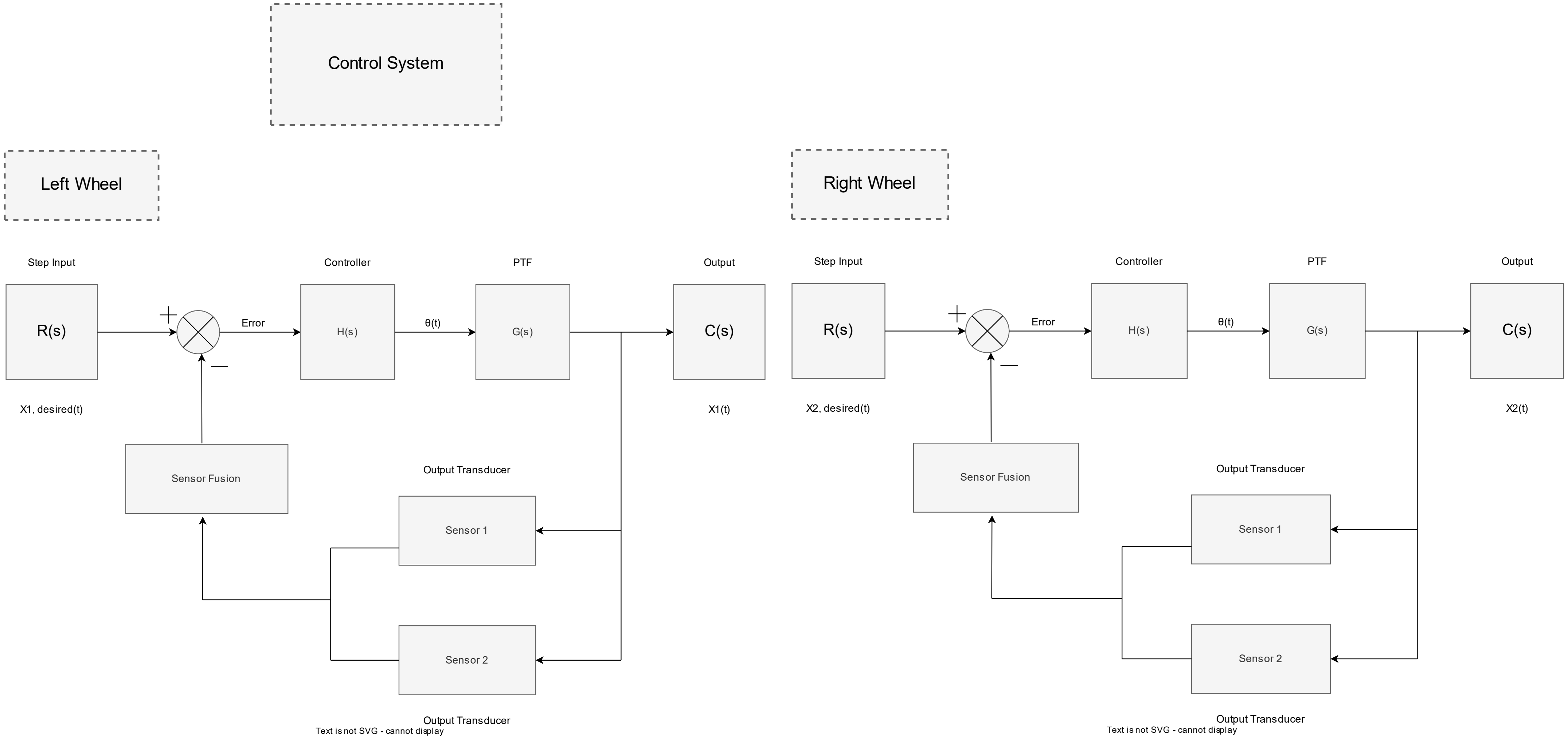
Aaron Havener

Control System Structure



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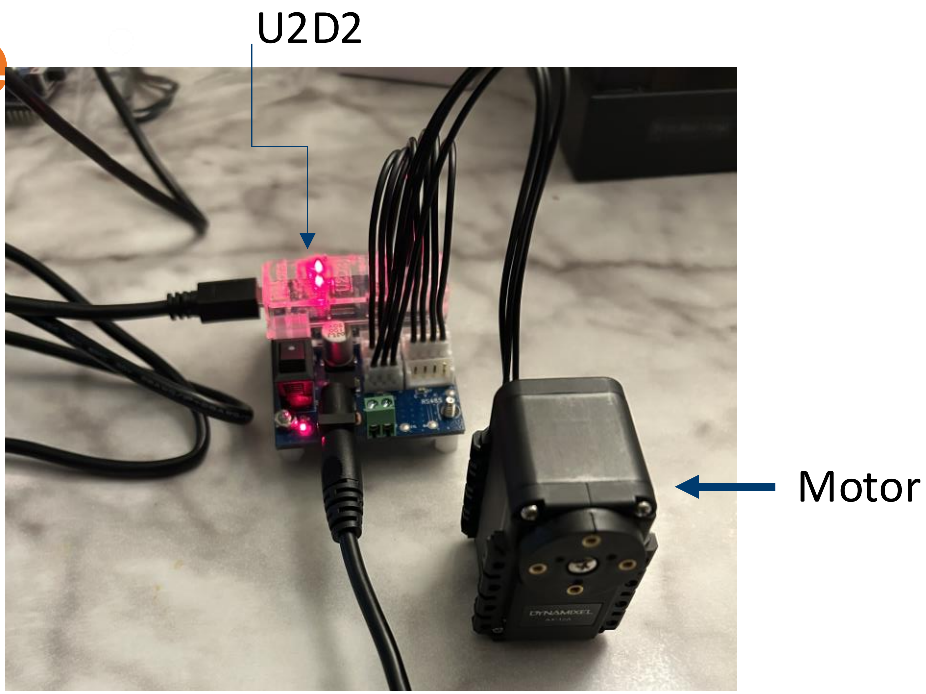
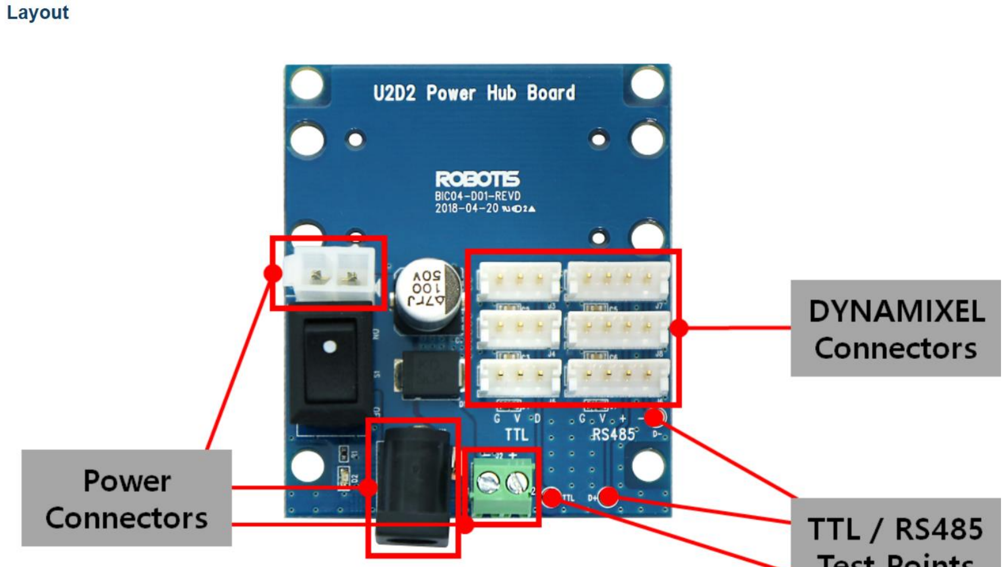
Motor Control Update

Aliya Hutley

- Successfully controlled the motors and recorded their position vs time.
- Motors were actuated and tested using DYNAMIXEL Wizard software to change IDs and perform basic movements. Components included:U2D2 via USB, Power hub board, AX-12A motor, Wall outlet Power Supply
- “U2D2 is a small size USB communication converter that enables to control and operate DYNAMIXEL with PC.”(Robotis)



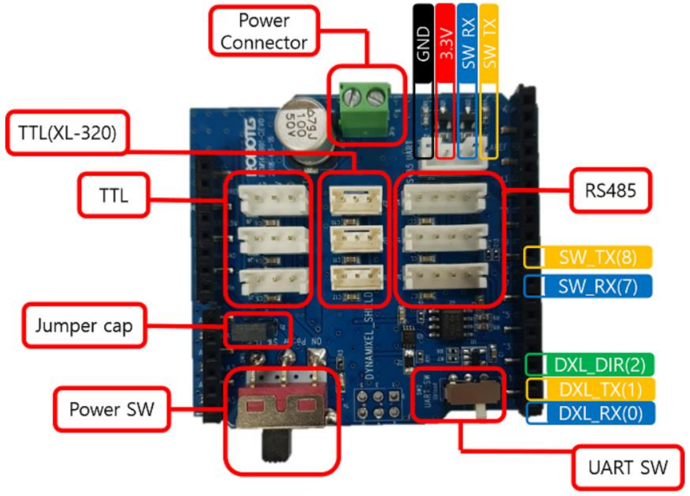


Graphic layout of DYNAMIXEL U2D2 Power Hub (ROBOTIS)

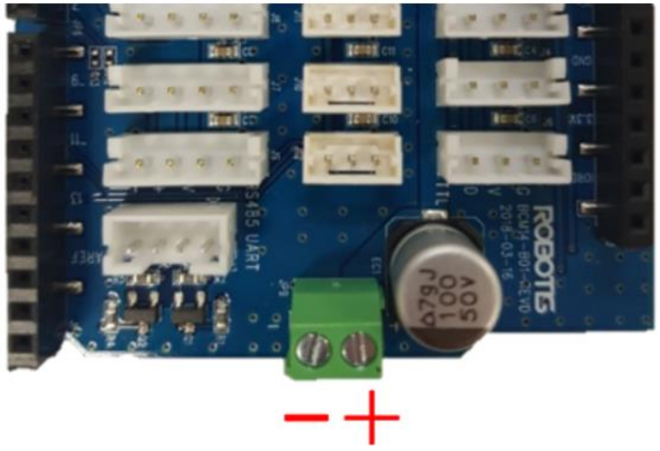
Aliya Hutley

Motor Control: Challenges

- Motor require more power than what Arduino microcontrollers can provide. Arduino is limited to 5V output, while motors require around 11.1V resulting in adequate power.
- Motors do not actuate when powered solely by Arduino with the DYNAMIXEL shield (component that allows motors to use Arduino).
- Solution: Use an external power supply (12V battery with appropriate adapter) to provide power directly to the shield using the Power Connector rather than Arduino.



Graphic layout of DYNAMIXEL SHIELD (ROBOTIS)



Shield

Arduino Mega

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Font Check

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