FAMU-FSU College of Engineering

Design Review 5

Team 515 – Controllable CVT Device

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

02/18/2025

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

FAMU-FSU
College of
Engineering

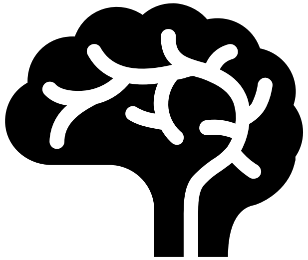
Objective

The objective of this project is to enhance the education of haptic robotics 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.

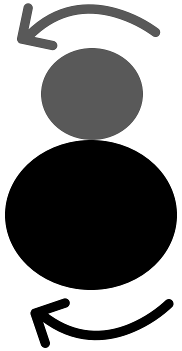
Kemani Harris

Recap

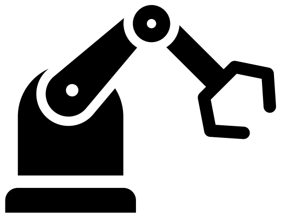
The primary goal of this project is to utilize CVT technology to present to STEM-curious students:



General autonomous robotic technology



The mechanical principle of CVT's



The use of CVT's in robotics

FAMU-FSU College of Engineering

Recap

Other key design goals have been and still are:

Precise, autonomous two-dimensional movement

Customizable, well-displayed, and engaging output

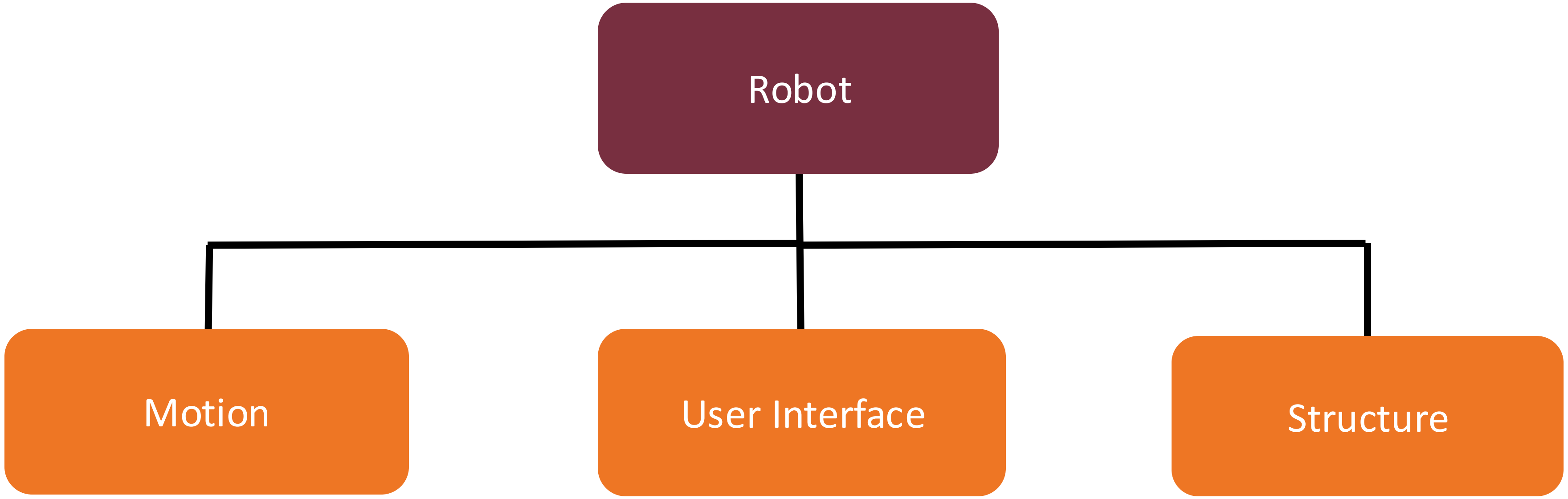
Use in multiple locations

FAMU-FSU College of Engineering

Kemani Harris

Recap

Three main systems are employed:



Kemani Harris

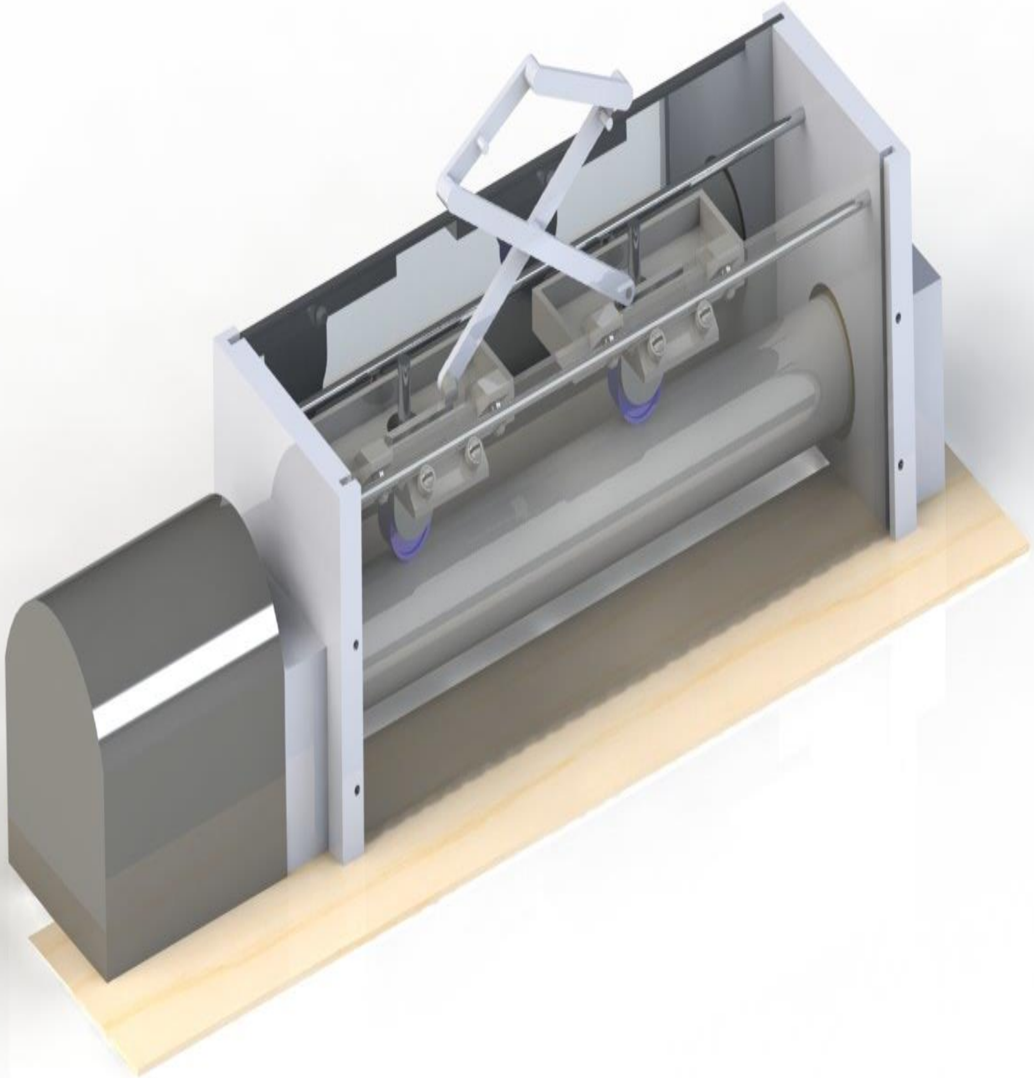
Proposed Concept

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

FAMU-FSU College of Engineering

General Design Update

Kemani Harris

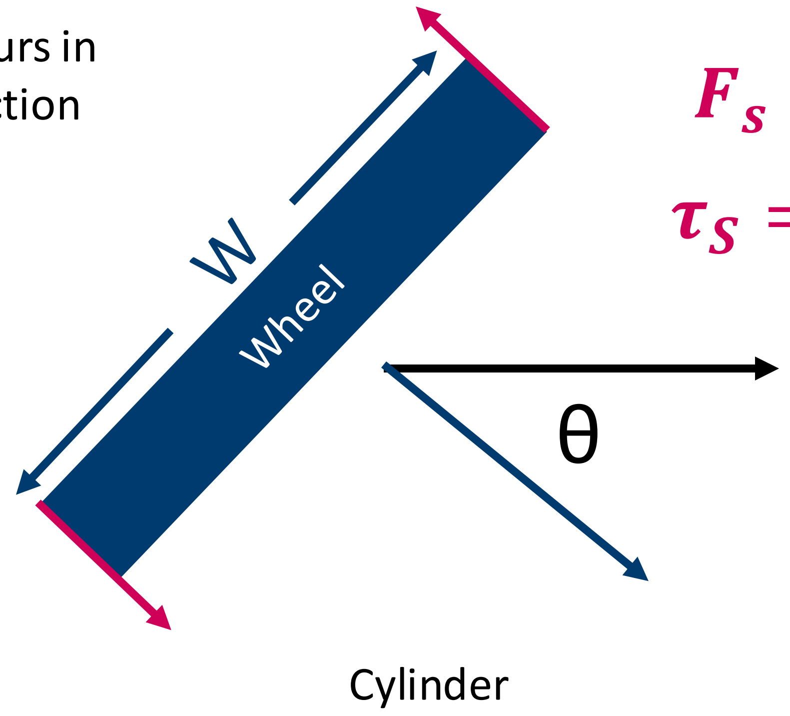


Motion System – Steering Motor Selection

Aliya Hutley

Steering motors are oversized to allow for flexibility in preload

Note: Steering occurs in the clockwise direction



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

$$\tau_S = F_s W$$

FAMU-FSU College of Engineering

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

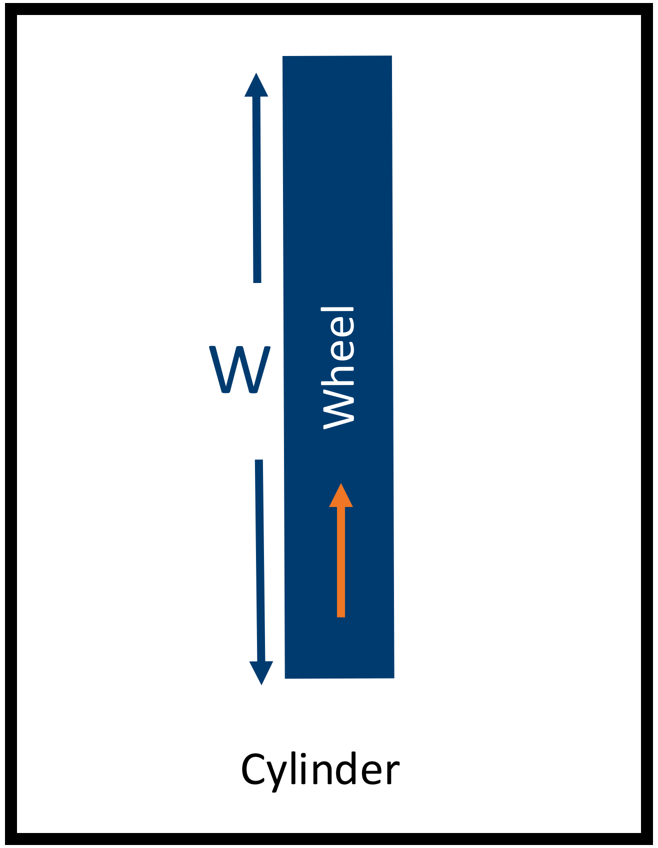
Aliya Hutley

Driving torque was calculated from frictional forces

$$\theta = 0°$$

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

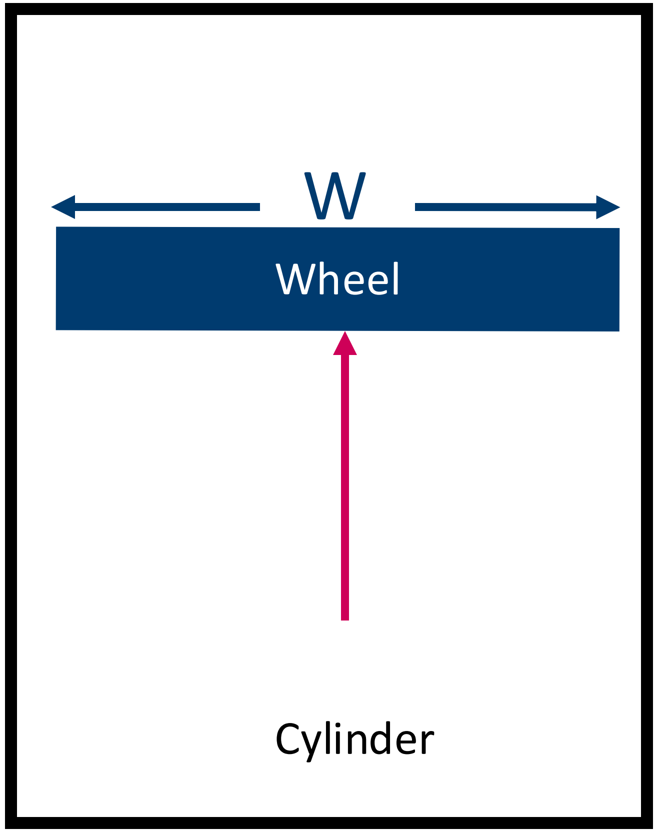
$$F_{slide} = 0$$



$$\theta = 90°$$

$$F_{roll} = 0$$

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



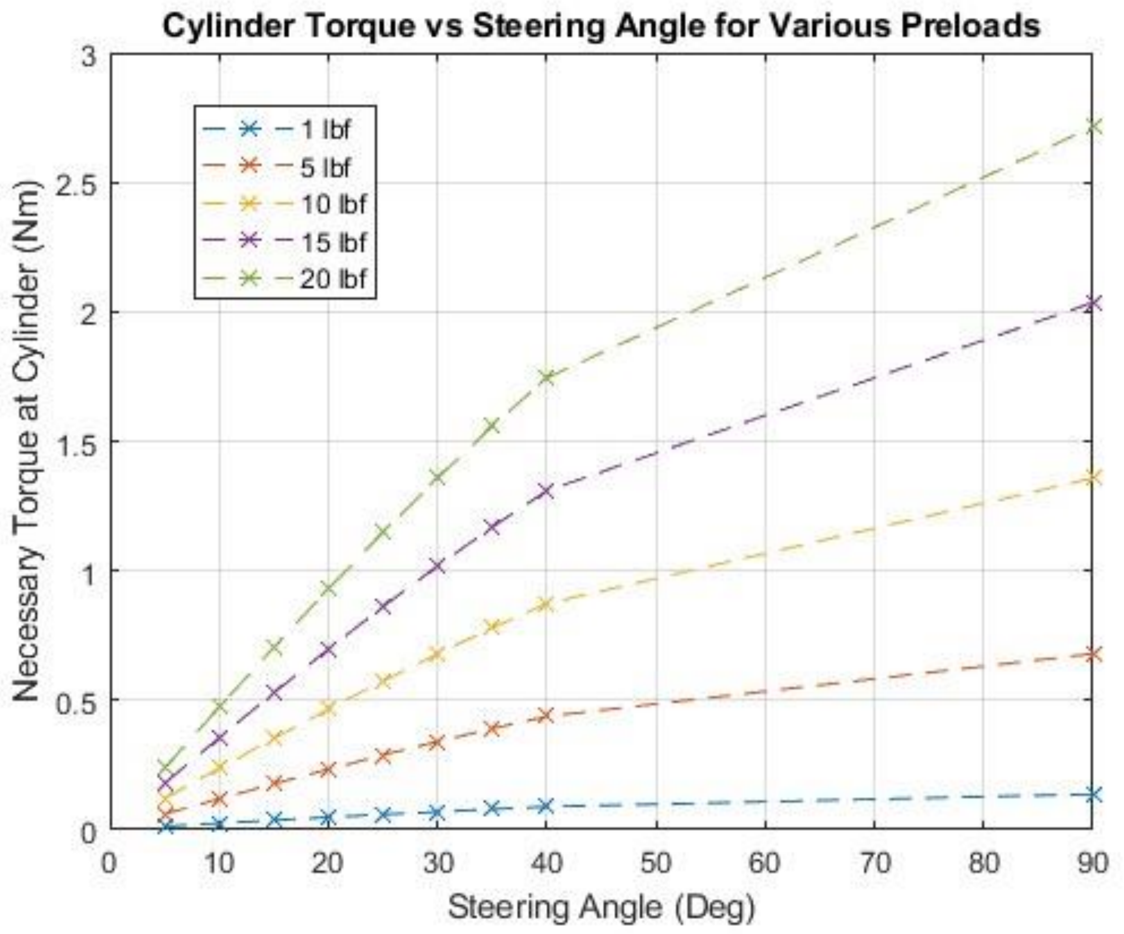
FAMU-FSU College of Engineering

Motion System – Driving Motor Selection

Aliya Hutley

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

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



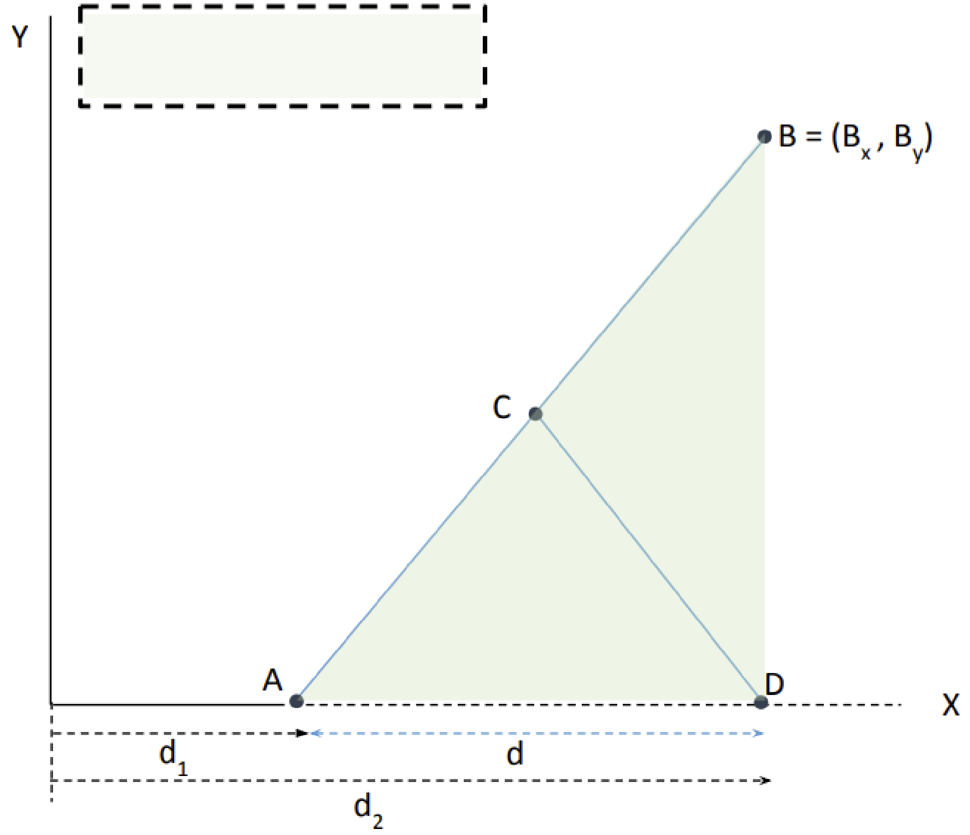
Aliya Hutley

Motion System – Driving Motor Selection

- With a preload of 15 lbf at a 90°steering angle, the necessary driving torque is estimated to be around 2 Nm
- A Crouzet direct current gearmotor that can provide 2 Nm at 50 rpm is the current selected motor

Kemani Harris

Linkage Design – Prototype 0

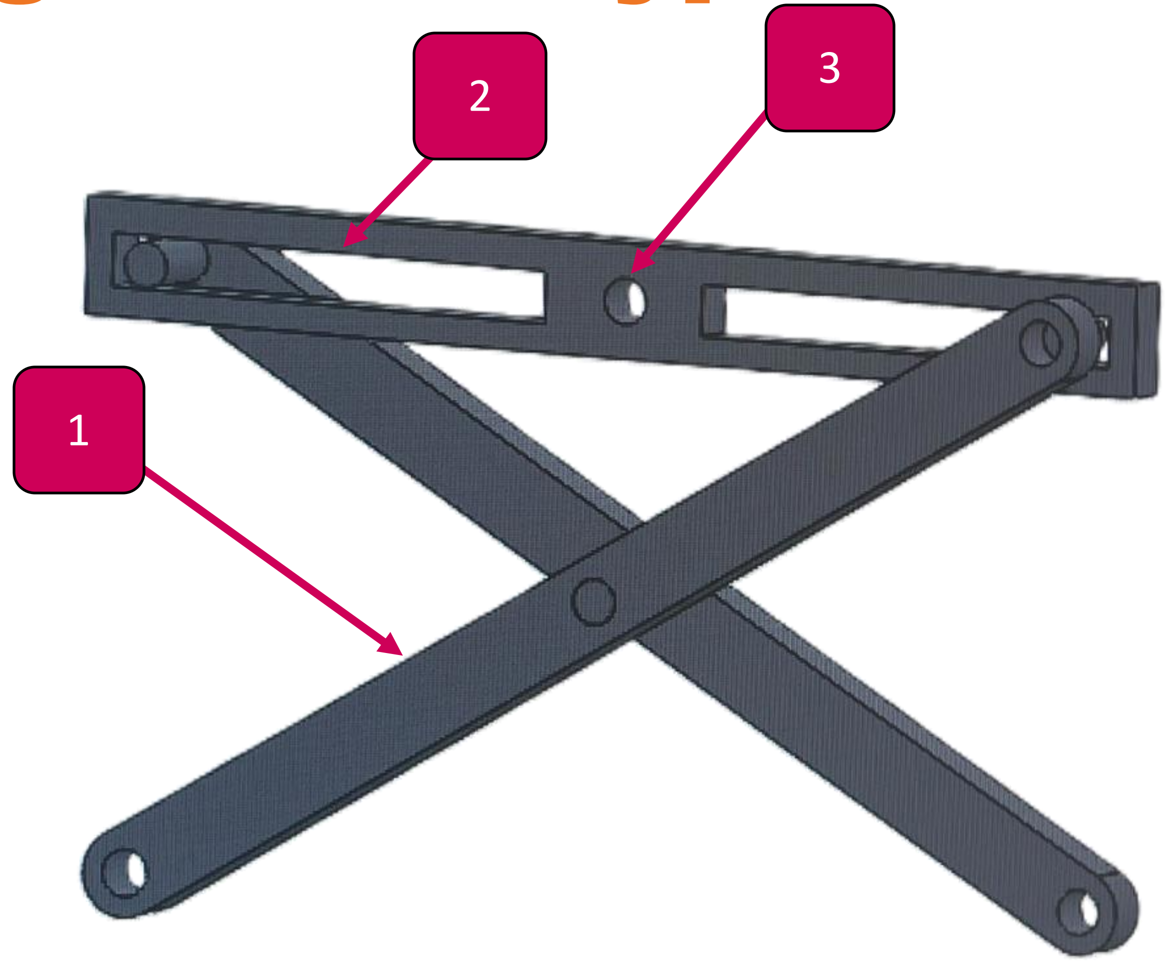


Linkage Design – Prototype 1

1) Equal Link Length

2) Slider Linkage

3) Middle Coupler Point



FAMU-FSU College of Engineering

Linkage Design – Prototype 1

Downside

- 3 Degrees of Freedom
- Stabilization
- Waste of Resources

FAMU-FSU College of Engineering

Kemani Harris

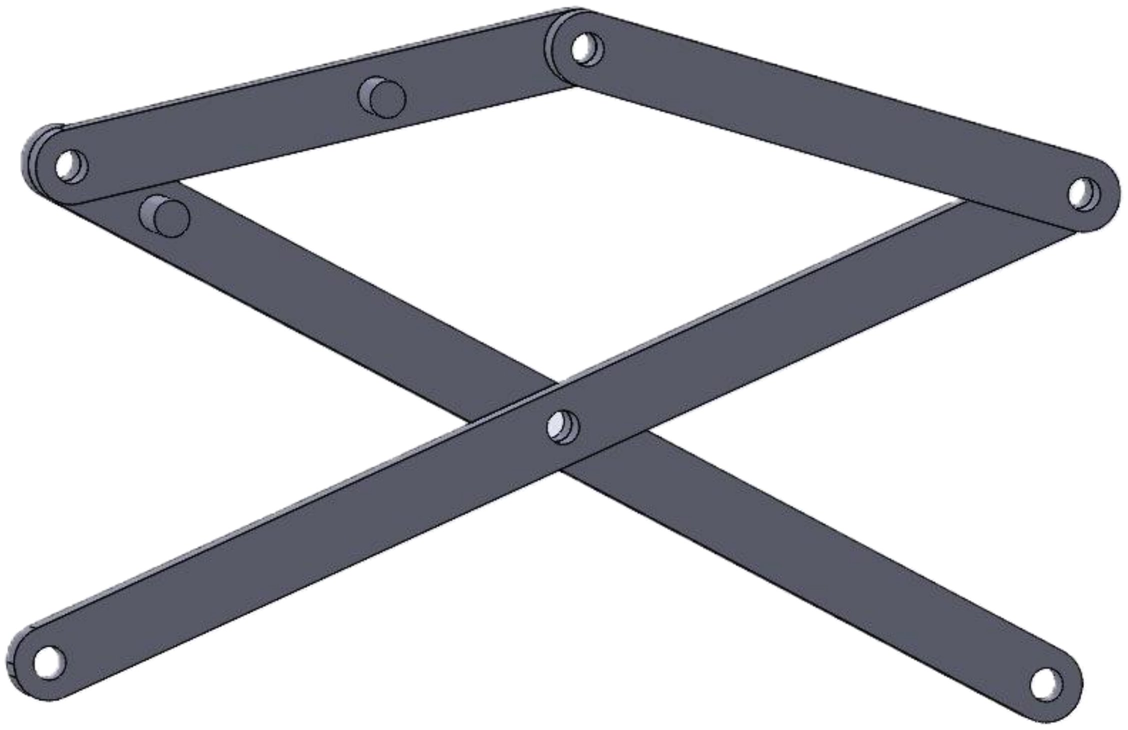
Linkage Design - Prototype 2

Smaller Link size

Enhances vertical motion

Reduces horizontal displacement

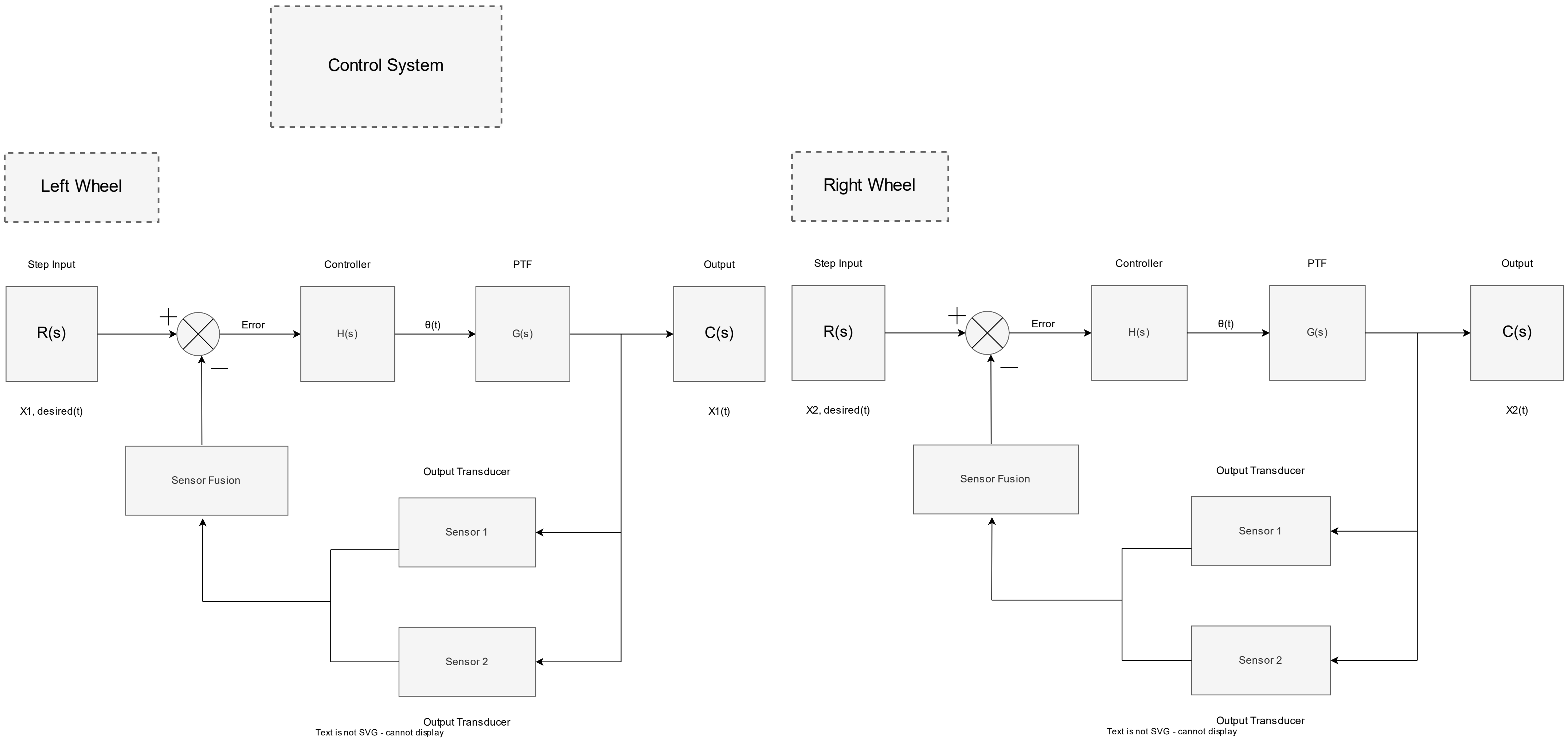
springs on joints



FAMU-FSU College of Engineering

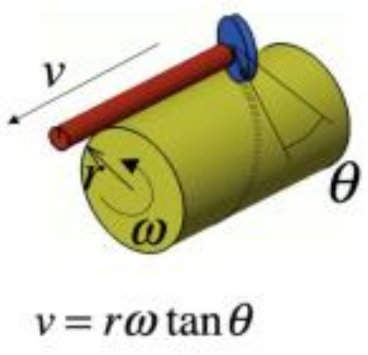
Aaron Havener

Control System Structure



FAMU-FSU College of Engineering

Controller Derivation



$$sX_1(s) = rwU(s)$$

$$Plant\ Transfer\ Function\ \frac{X(s)}{U(s)} = \frac{rw}{s}$$

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

$$\frac{dx_1(t)}{dt} = v = rwtan\theta$$

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

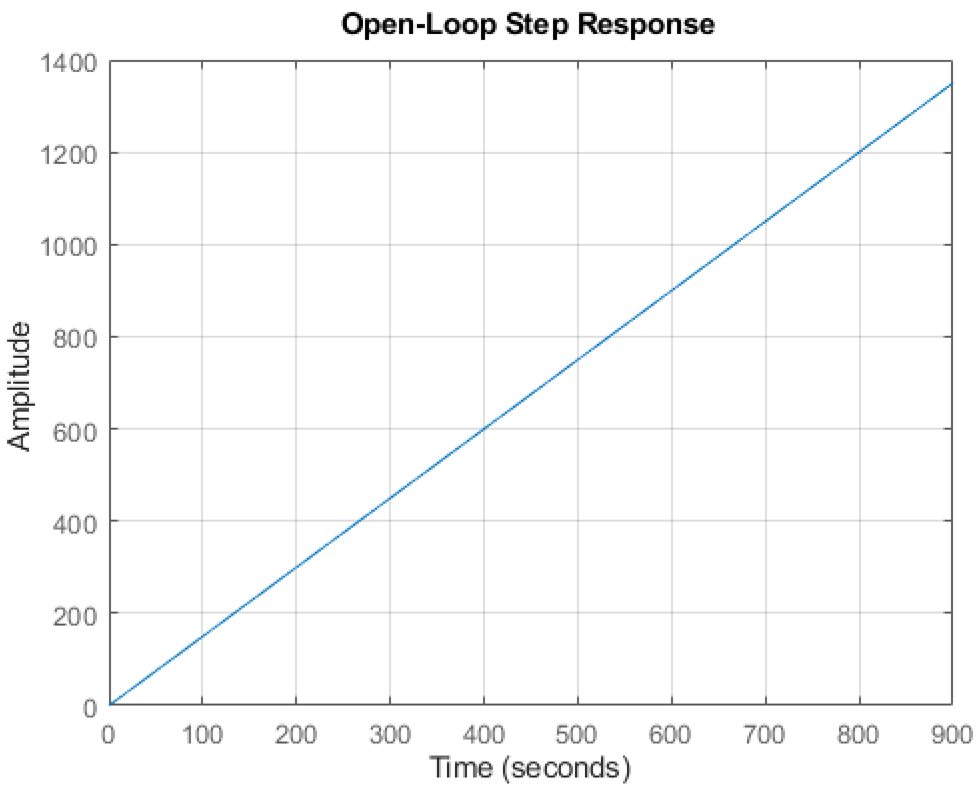
$$Control\ input\ u(t) = tan\theta$$

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

$$\frac{dx_1(t)}{dt} = rwu(t)$$

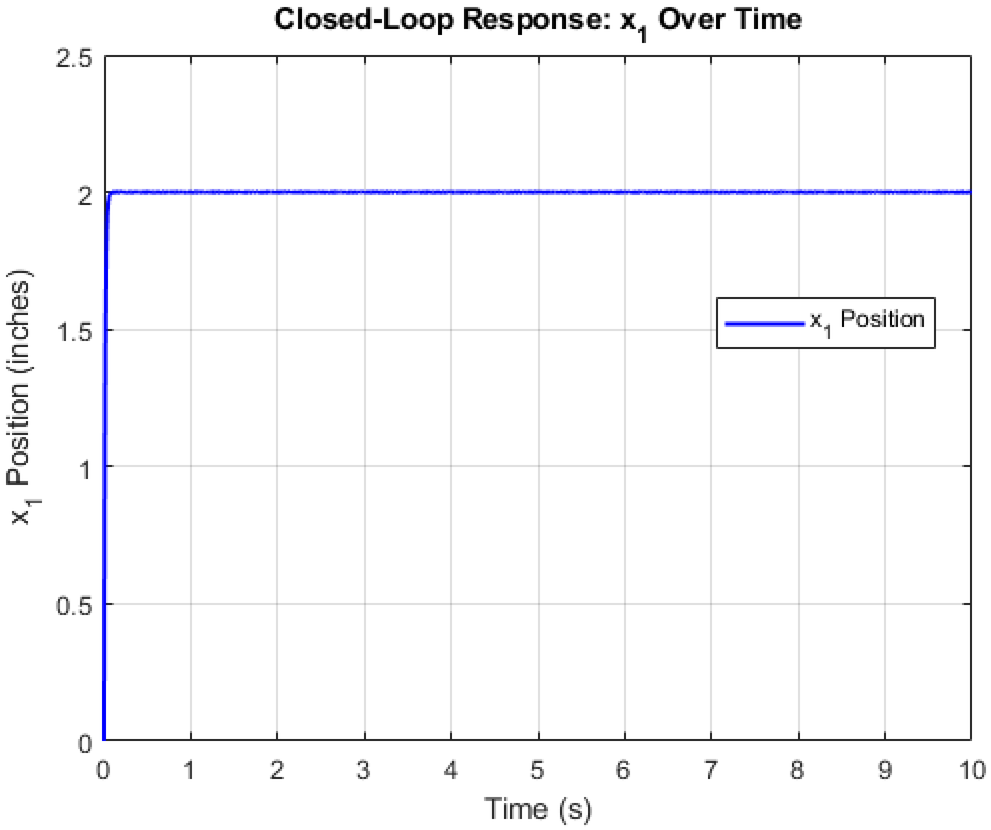
$$v = rwtan(\text{atan}\left(K\left(x_{1,desired}(t) - x_1(t)\right)\right))$$

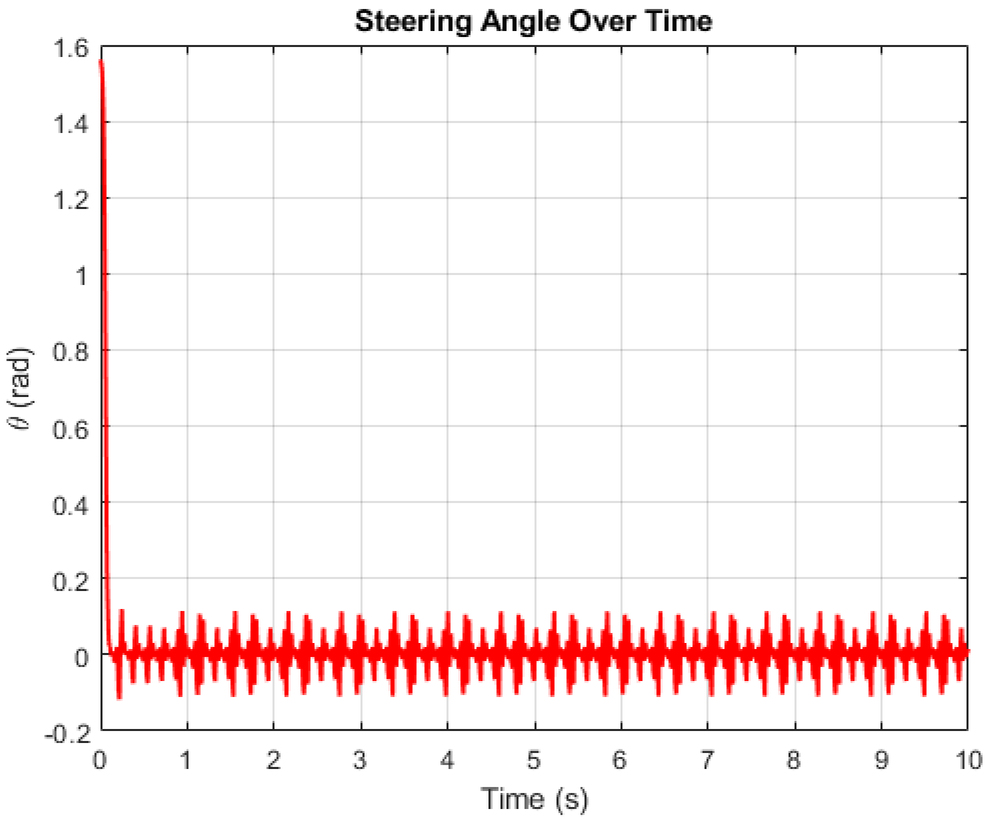
Need For Control



FAMU-FSU College of Engineering

Controller Results – Simple A to B Motion

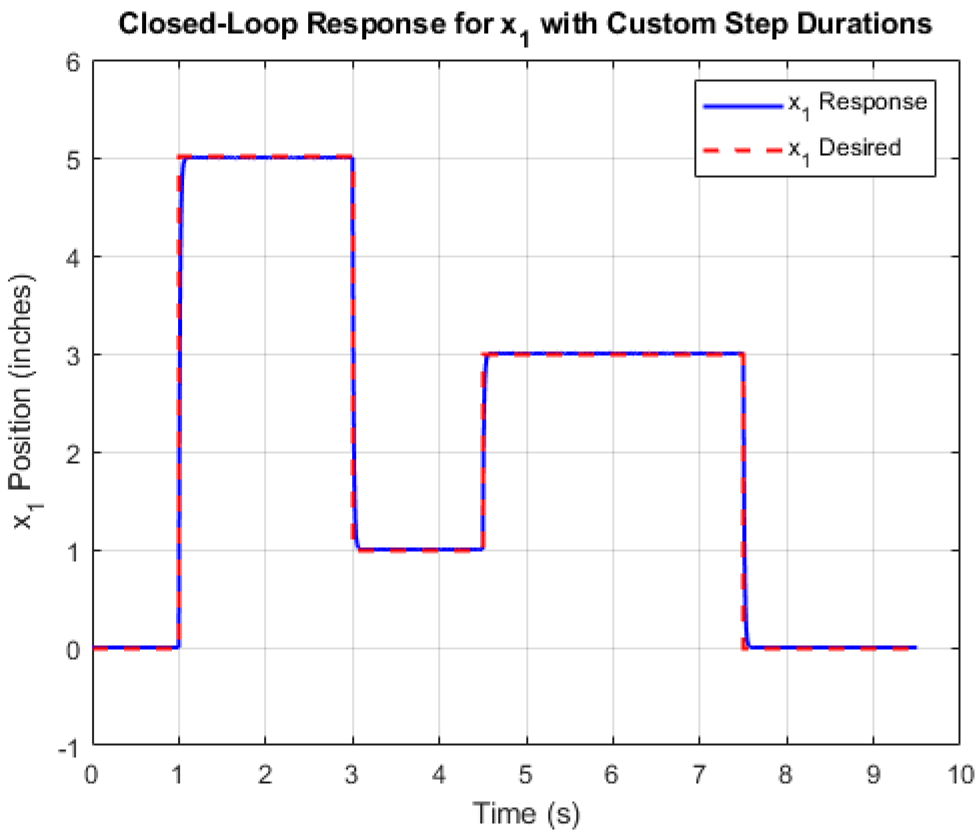


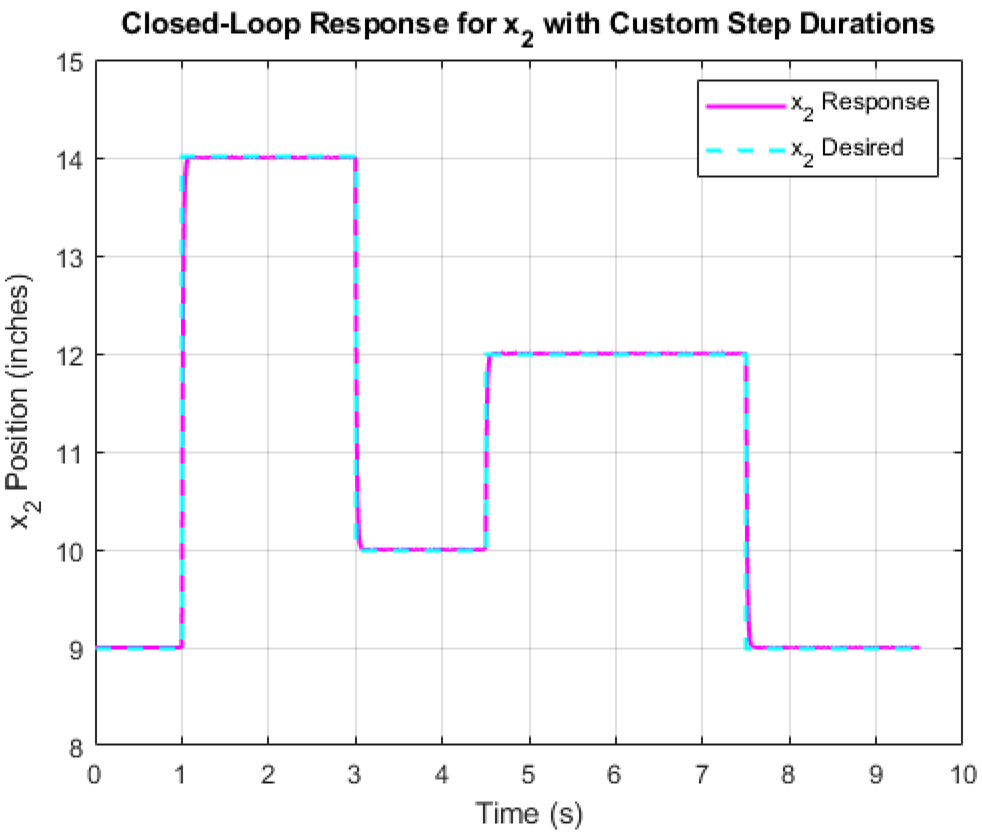


FAMU-FSU College of Engineering

Sequence of Desired Positions with Tuned Gain

Aaron Havener

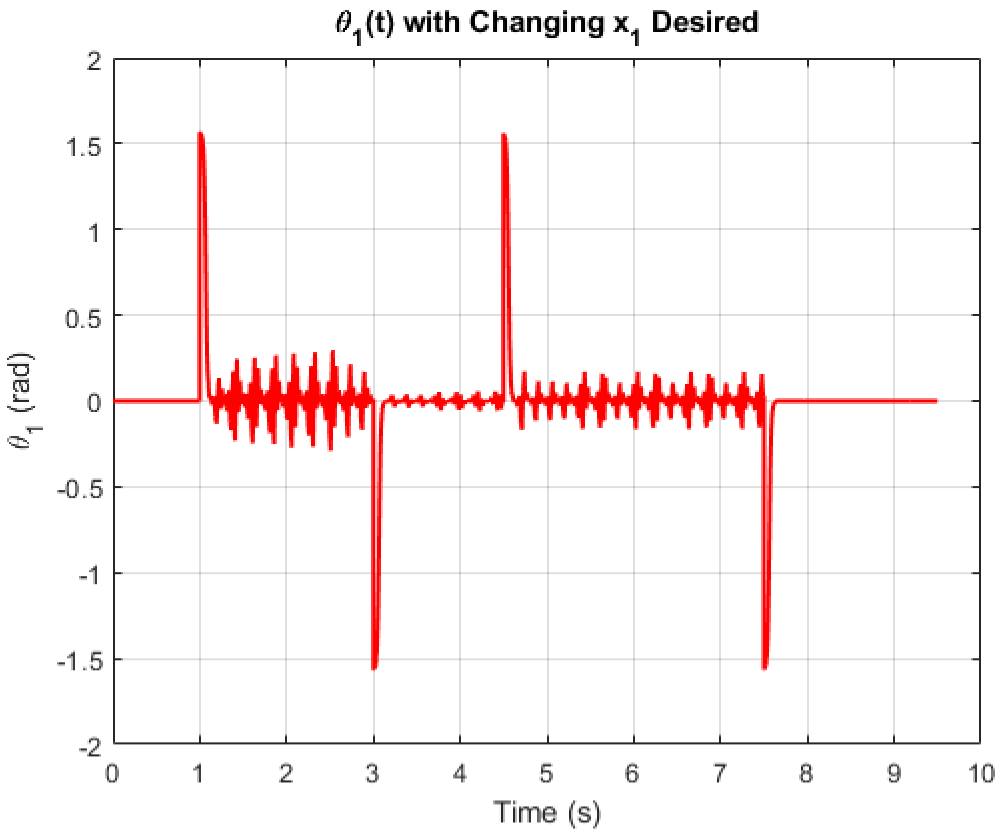


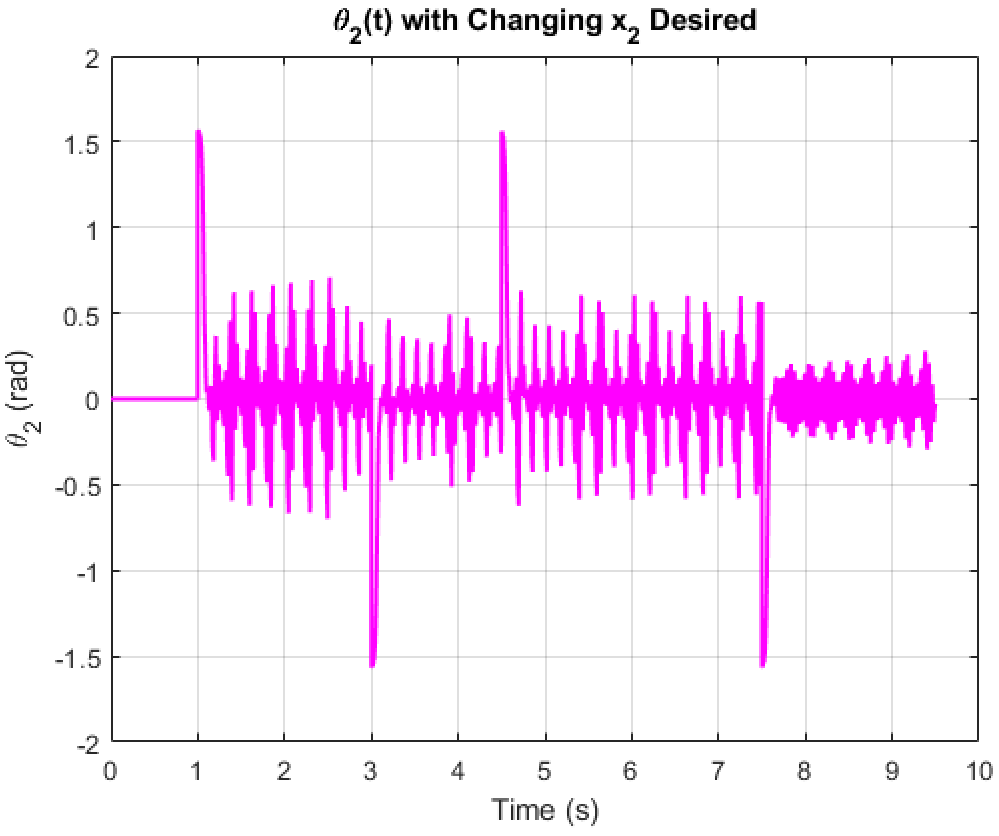


FAMU-FSU College of Engineering

Aaron Havener

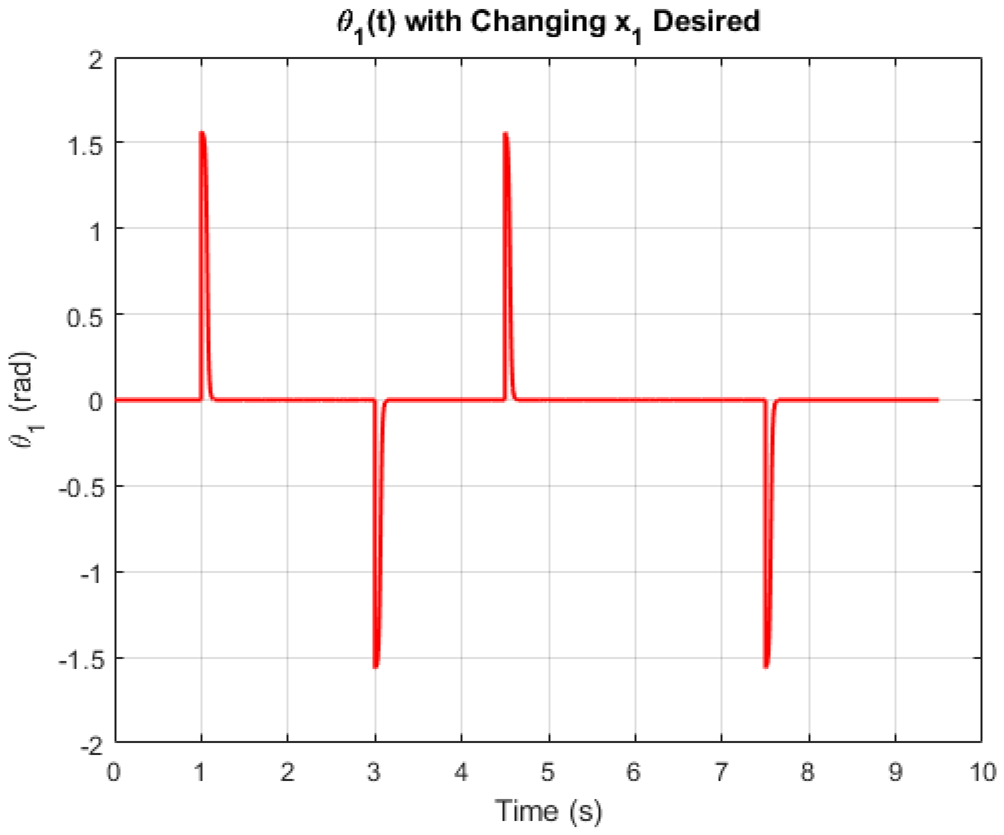
Error Accumulation

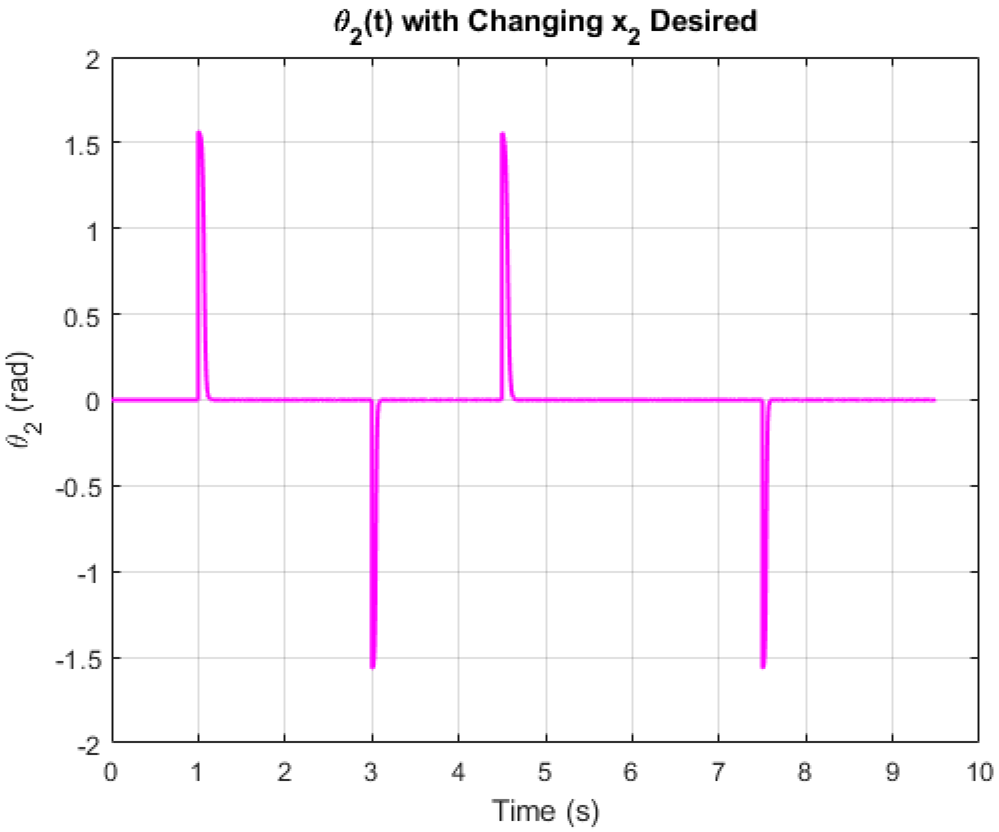




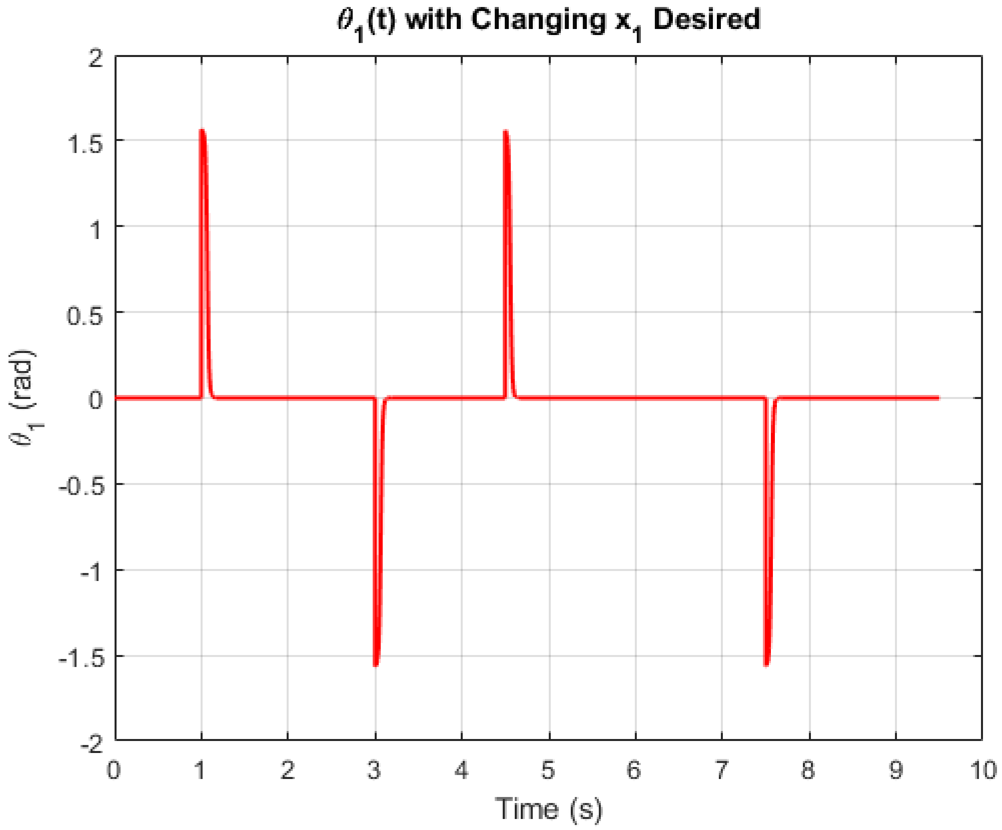
FAMU-FSU College of Engineering

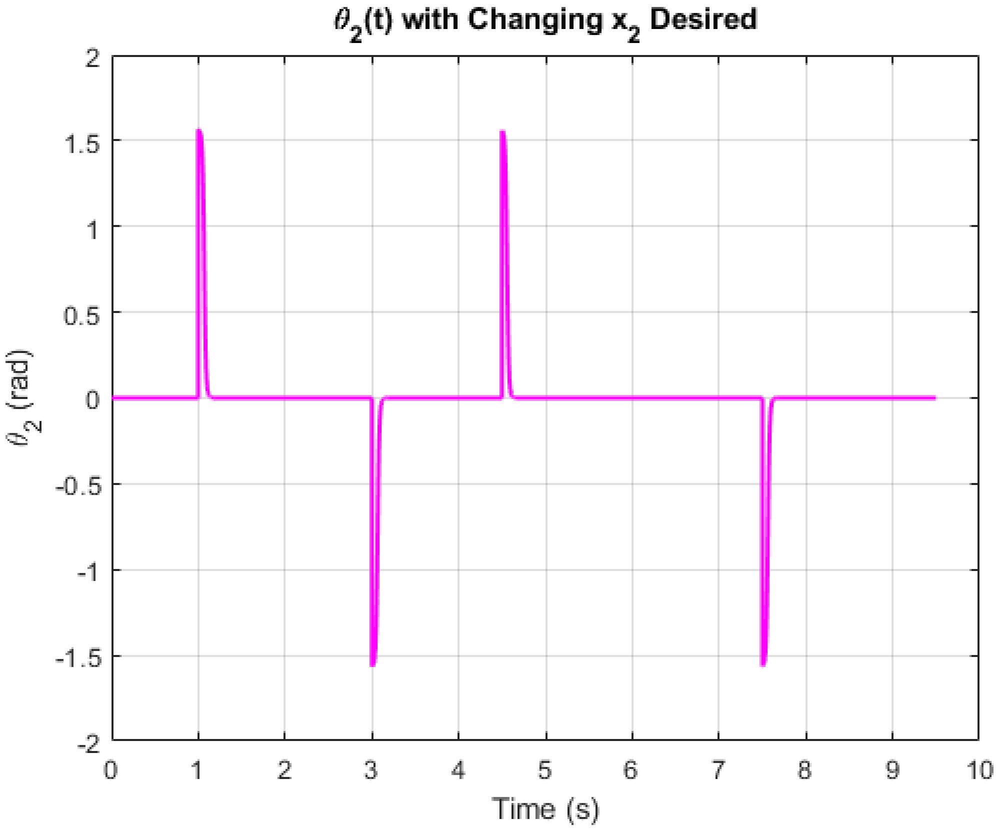
Proposed Solution



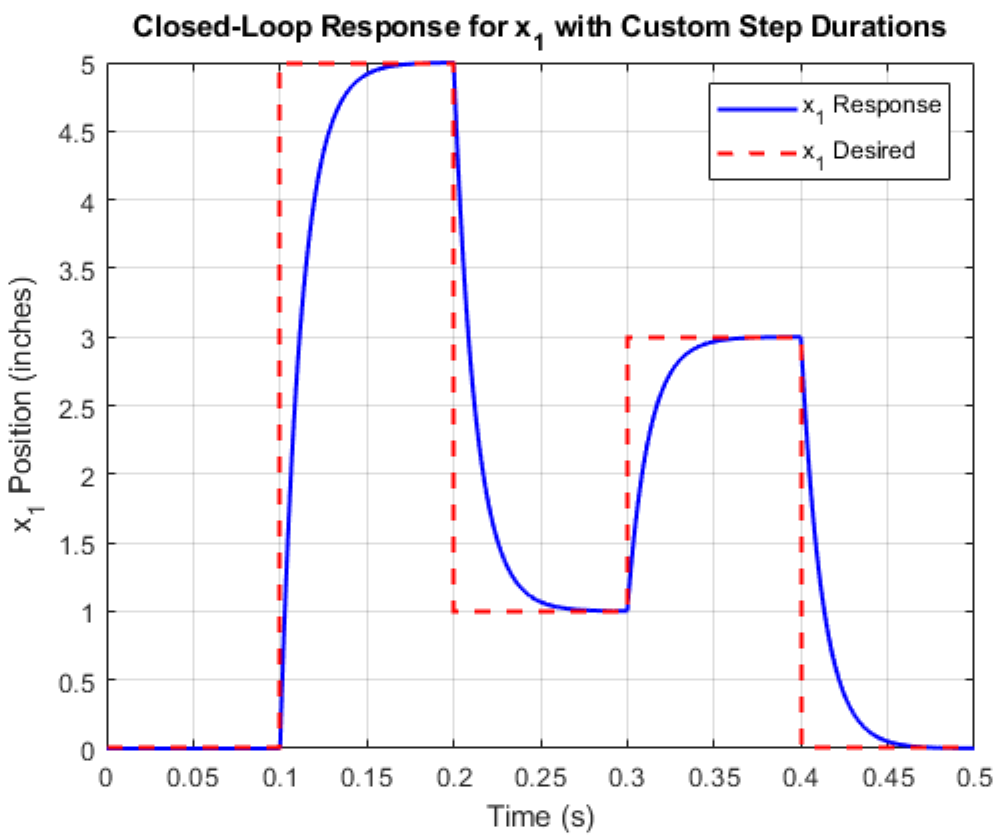


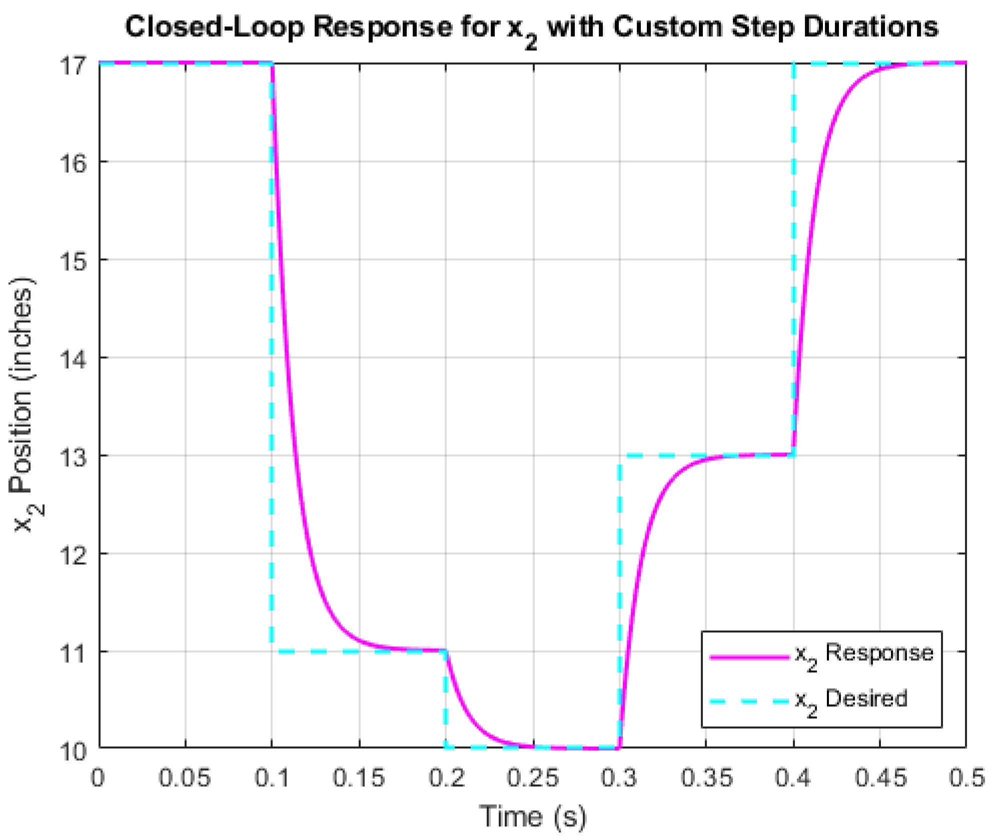
Proposed Solution - Modified





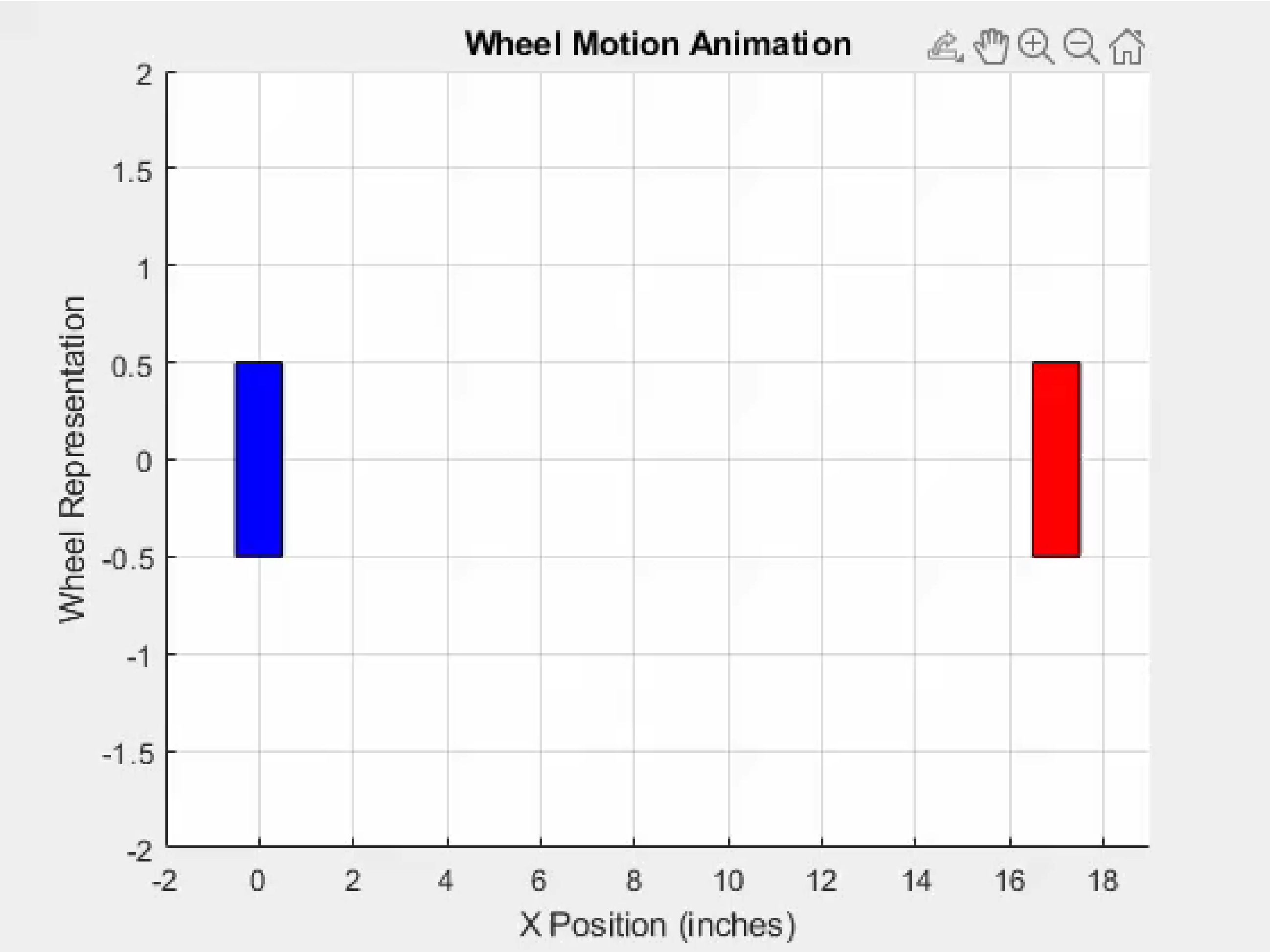
Decreased Time Step Response





FAMU-FSU College of Engineering

Simple Animation



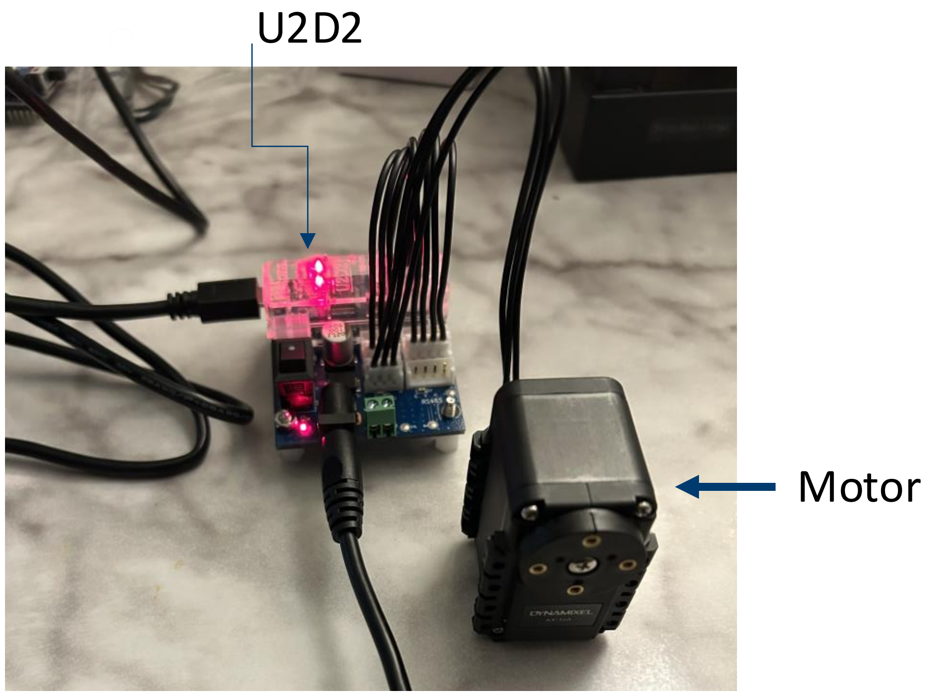
Controls Future Work

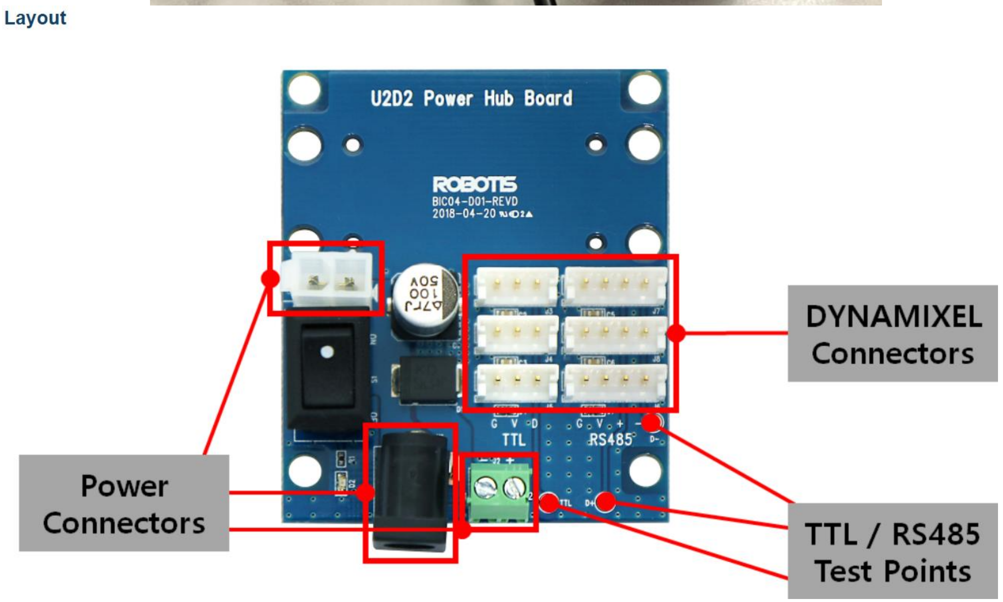
- Limit steering angle
- Determine desired x values as a function of end effector kinematics from the new linkage design to create shapes
- Incorporate sensors as x position values for feedback
- Tune gain further based on prototype testing results

FAMU-FSU College of Engineering

Motor Control

- 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)

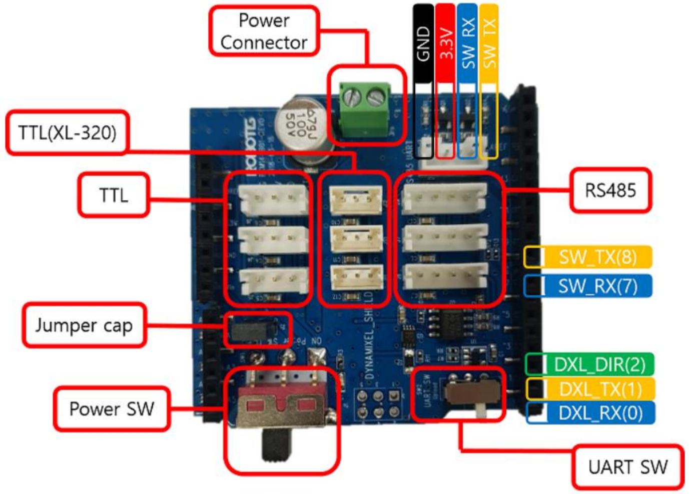
Aliya Hutley

FAMU-FSU College of Engineering

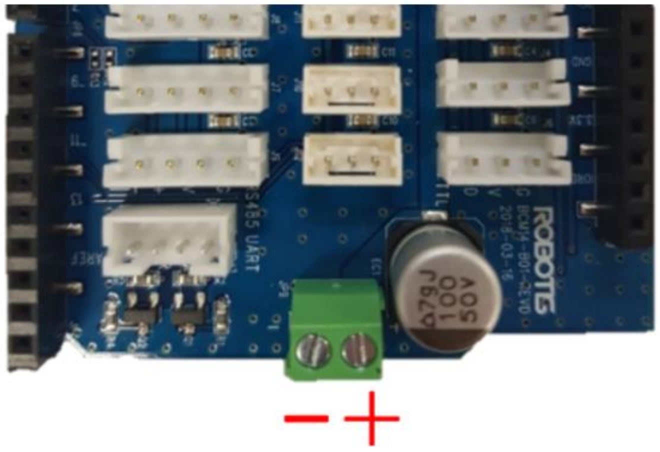
Aliya Hutley

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)



FAMU-FSU College of Engineering

Future Works – What To Expect Next Time?

Aliya Hutley

Motion System:

- CVT cylinder driving method selected
- Controller tuning
- Daisy Chaining Motors using Arduino Library Example and proper setup
- Replace use of linear potentiometers with laser sensors

User Interface System:

- Integration with structure and motion systems
- Replace use of LCD screen with OLED screen

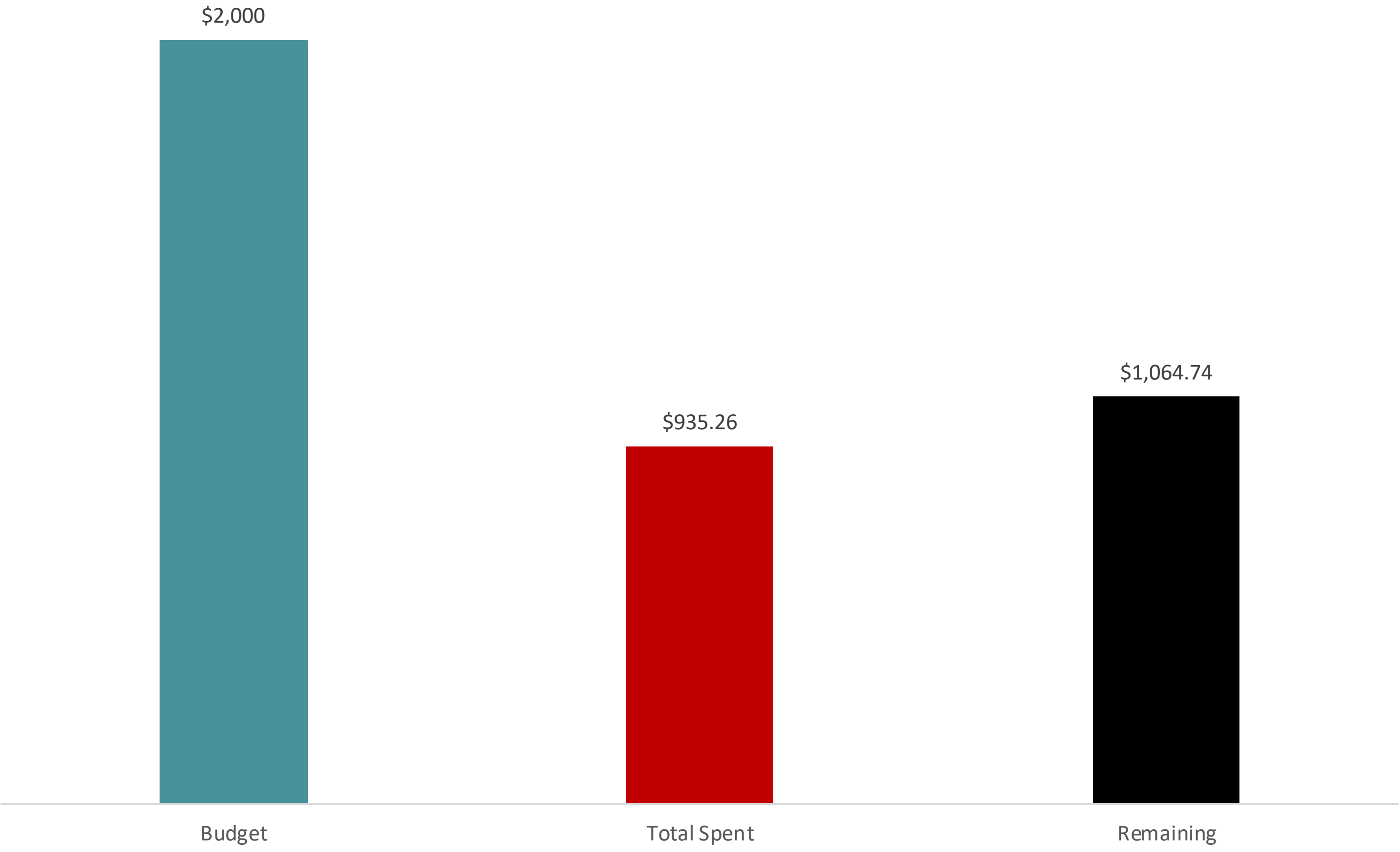
Structure System:

- Finalize base design with adjustable preload, sized carriages and linkages, and safeguarding

FAMU-FSU College of Engineering

Aliya Hutley

Thank You



FAMU-FSU College of Engineering

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.

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

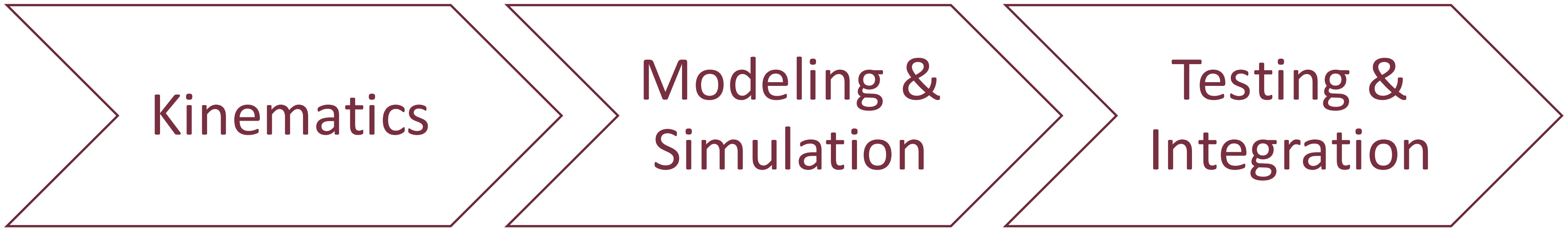
Dynamixel eManual:ROBOTIS. (n.d.). www.robotis.us

FAMU-FSU College of Engineering

Back Up Slides

FAMU-FSU
College of
Engineering

Future Works – What To Expect Next Time?



FAMU-FSU College of Engineering

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

FAMU-FSU College of Engineering

Font Check

- This is 10-point
- This is 15–point Times
- This is 20–point
- This is 25–point
- This is 30–point
- This is 35–point
- This is 40–point
- This is 50–point
- This is 60–point

FAMU-FSU College of Engineering