Hula Hooping Robot

Maheera Bawa, Michael Burgess, Sharmi Shah

2.74 FALL 2022
Bio-Inspired Robotics

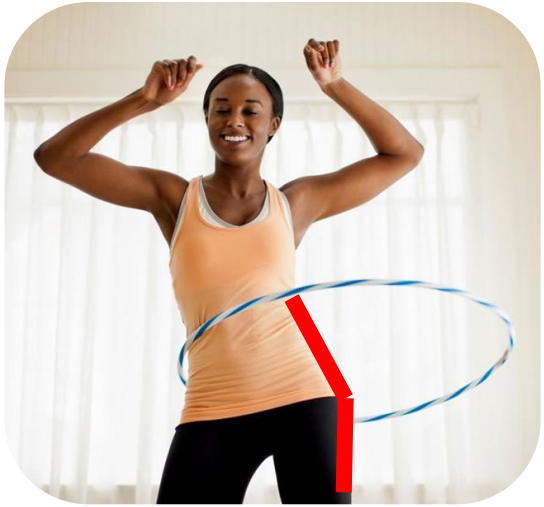
Hula Hooping?

How do humans hula hoop?

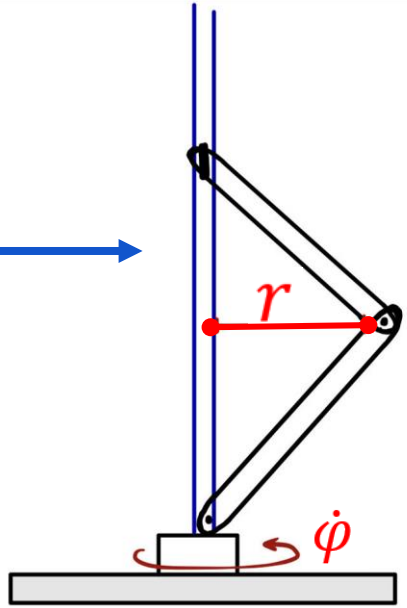
Can we mimic hula hooping with a robot?

Humans use a spiral trajectory for hula hooping

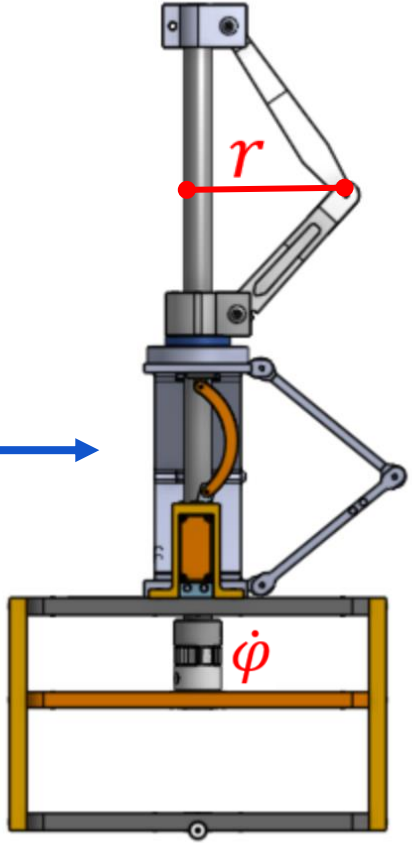
System Modeling



human



2 DOF
abstraction



final
system

Research Questions

How do we minimize *rise time*?

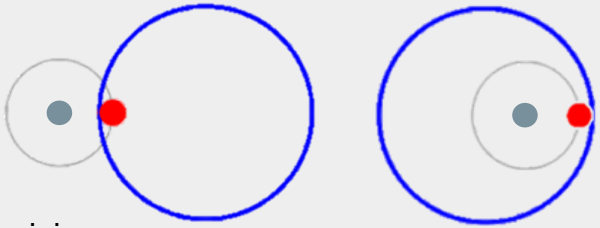
rise time

time it takes the hoop to reach steady state (rolling contact between hoop and “person”)

What is the optimal *phase difference*?

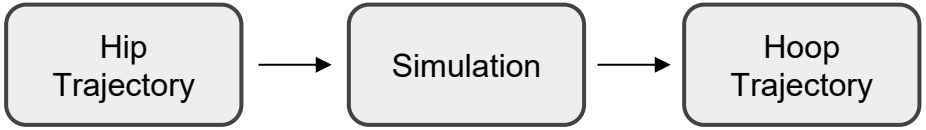
phase difference

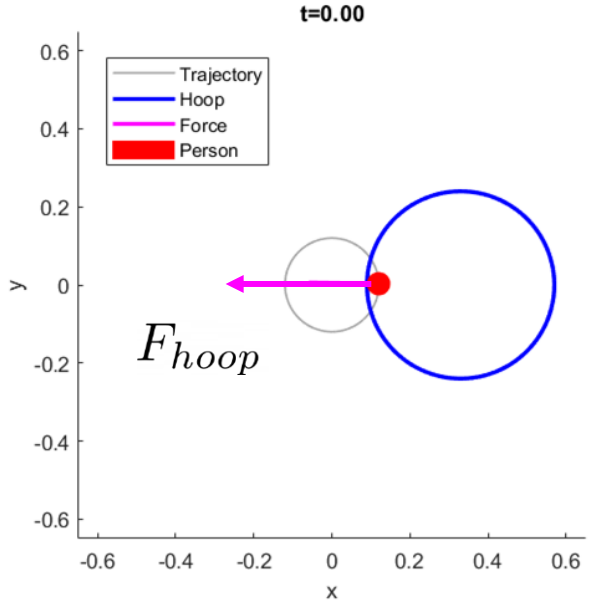
average angular difference between the hoop and person during steady state. e.g:



Simulation Methods

- Abstract to 2D for simplicity
  - No gravity!
- Input trajectory for our rigid-body person to see how hoop responds
  - Models hip as point moving through space

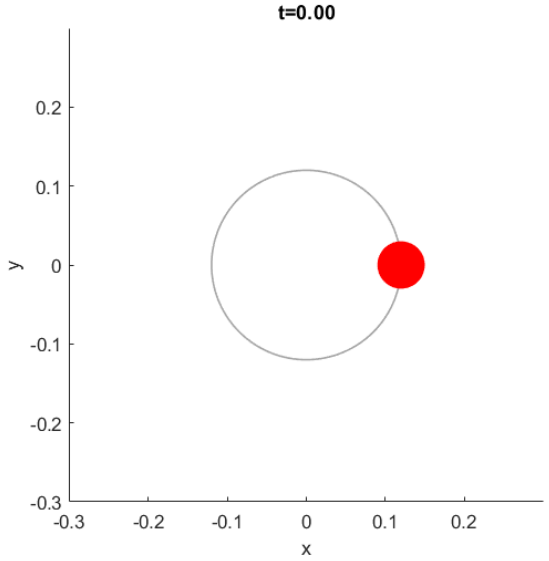




- Impose contact dynamics using spring-damper model…

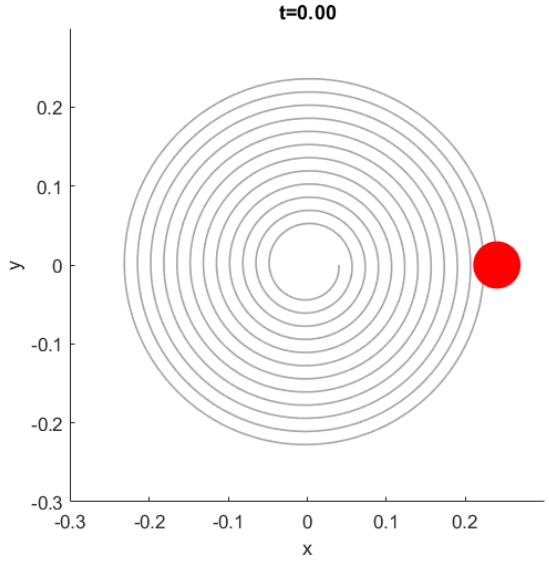
$$F_{hoop} = (Kx_{error} + D\dot{x}_{error})\hat{n}_r$$

Trajectories



Circular Trajectory

Radius: 0.5

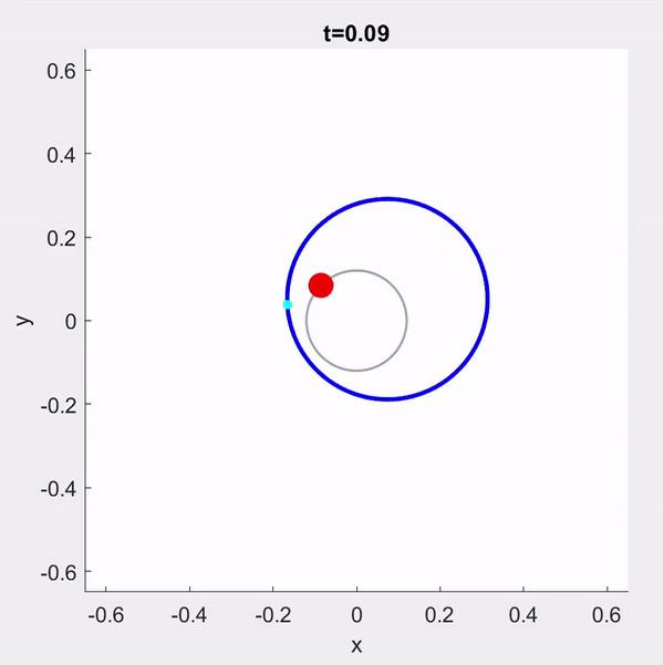


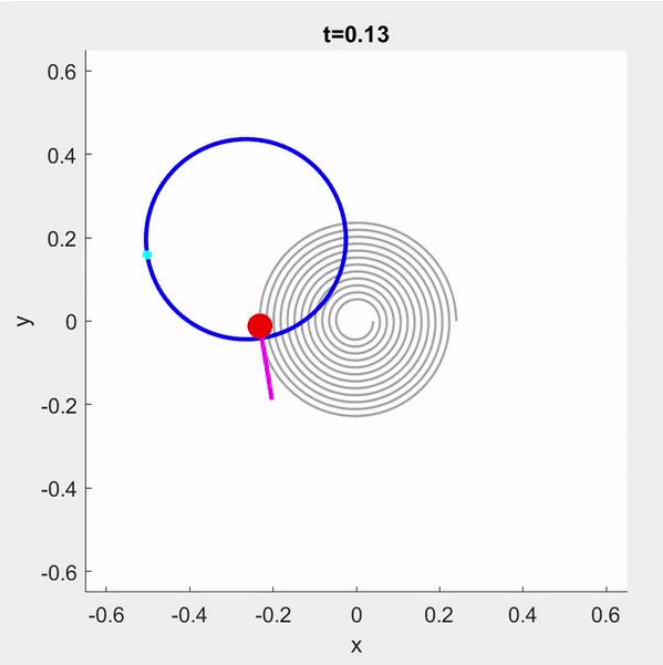
Spiral Trajectory

Start radius: 1

End radius: 0.1667

NOTE: Radius is normalized with respect to the hoop's radius





Circle

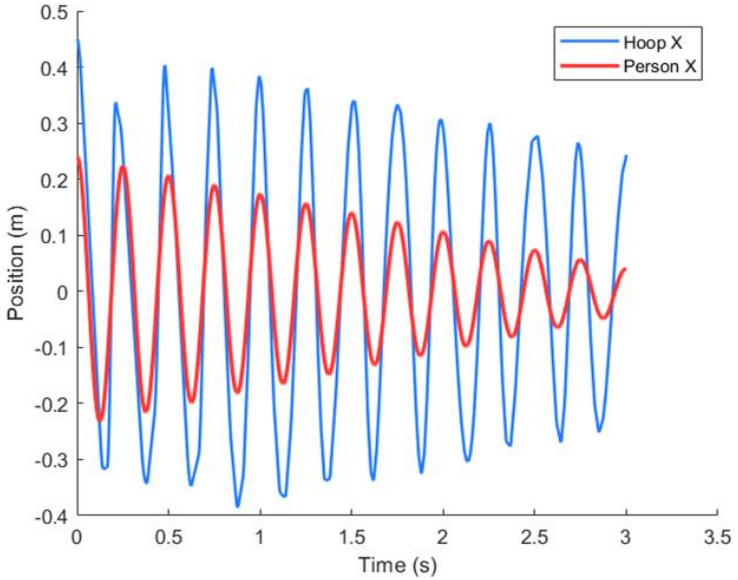
Radius:	0.5
Ang vel:	8π rad/s
Rise time:	0.86 s
Phase diff:	0.01 rad

Spiral

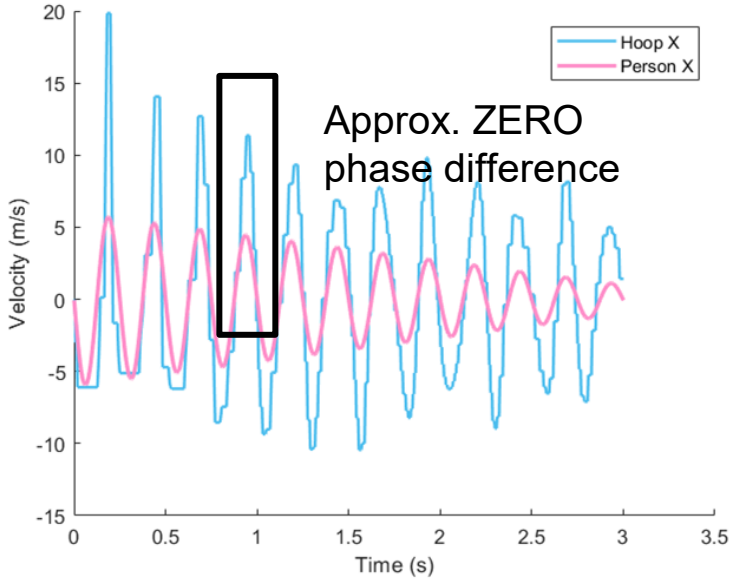
Start radius:	1
End radius:	0.1667
Ang vel:	8π rad/s
Rise time:	0.32 s
Phase diff:	0.04 rad

Simulation Results

Position



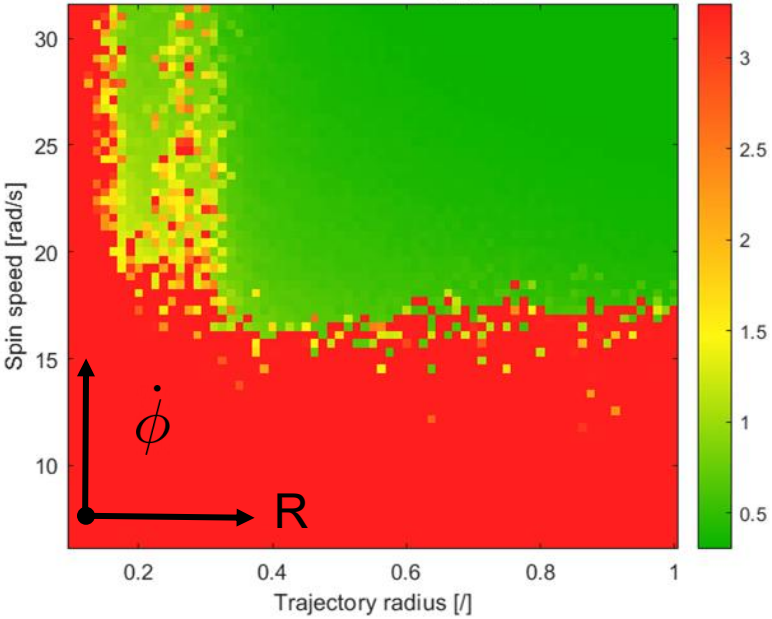
Velocity



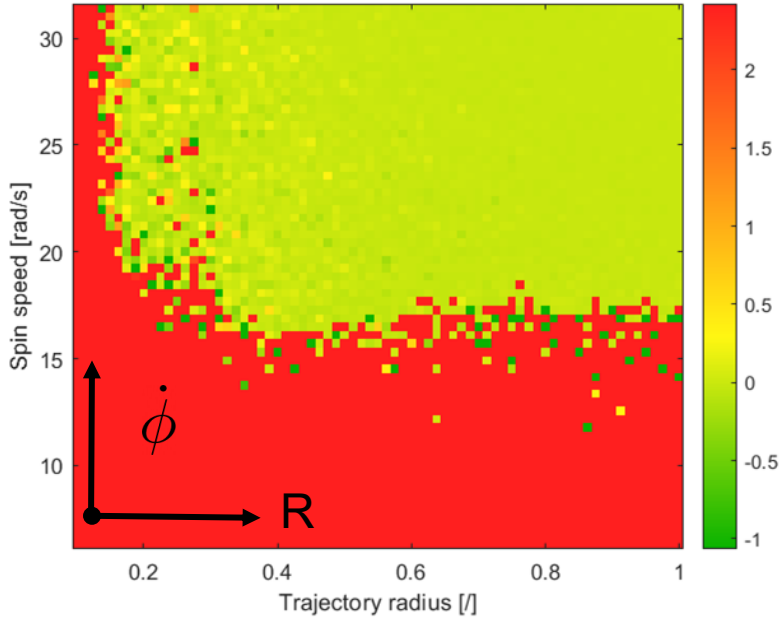
Simulation Results

- Ran sweep over circular trajectory parameters…

Rise Time [s]



Phase Diff. [rad]



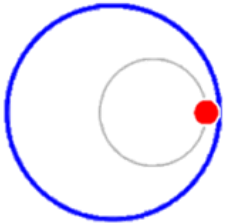
Rise time calculated by thresholding moving average of contact force.

Phase difference calculated as average over steady state period.

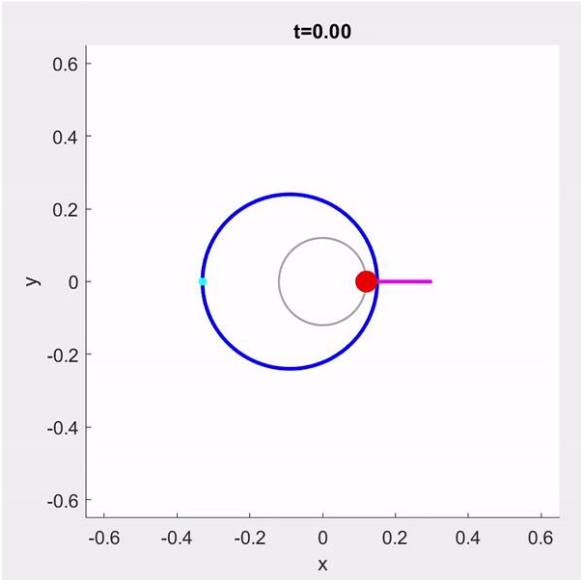
Phase Difference

- Originally, we expected a phase difference of π.
- Started at new initial configuration to confirm results…
  - Hoop naturally moves back to phase difference of zero!

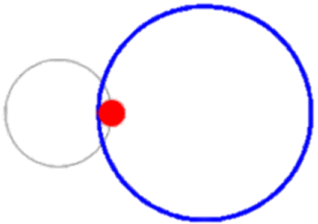
New Init. Config.
Phase Difference: π



t=0.0s

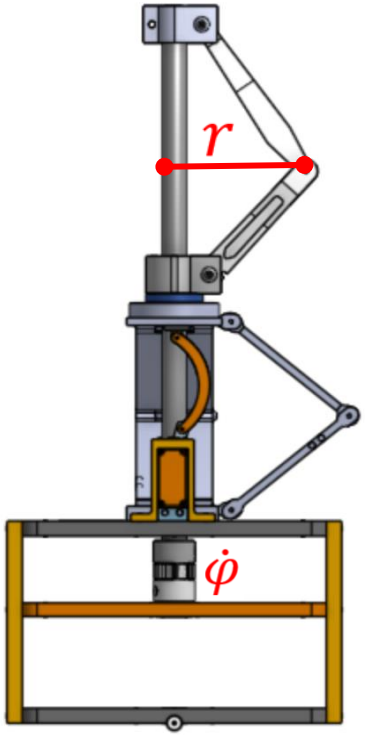


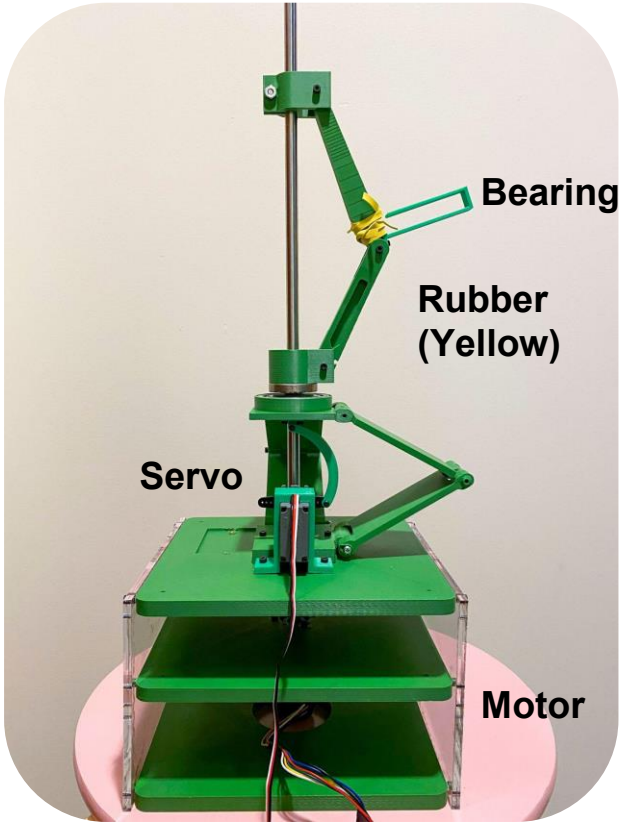
Final Config.
Phase Difference: 0!



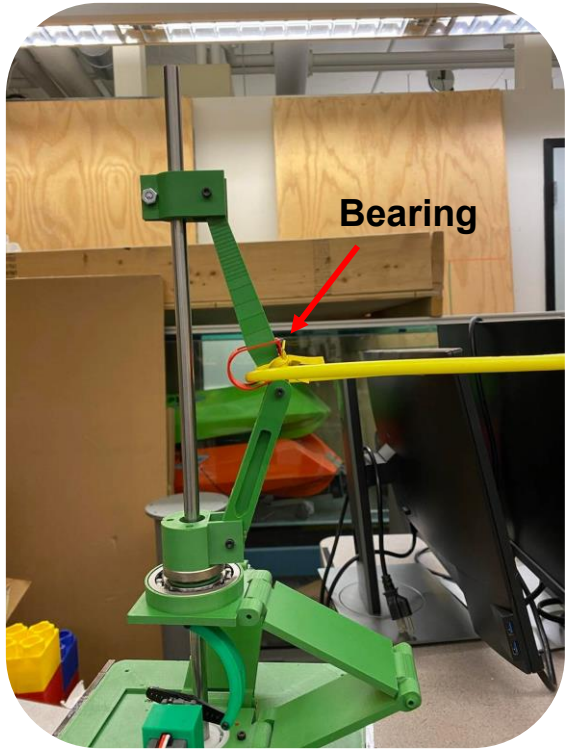
t=3.0s

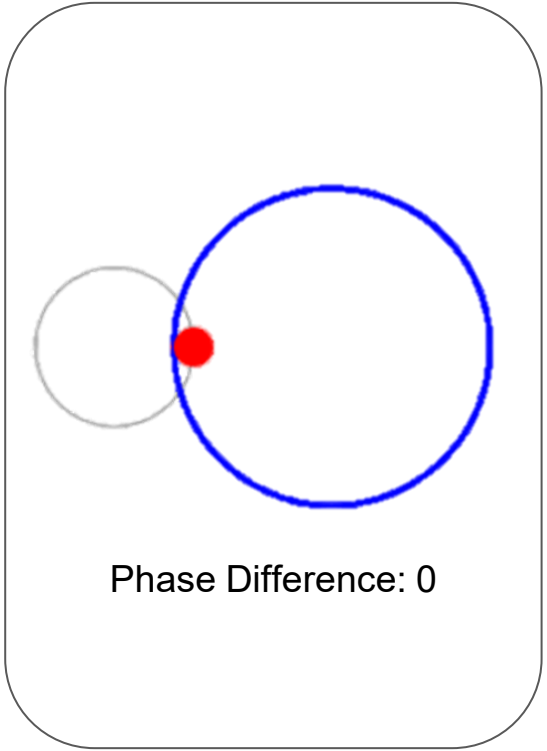
Experimental Methods: Hardware





Hoop Attachment

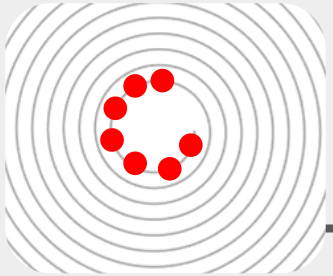




Bearing Purpose: constrain the hoop vertically while allowing it to spin

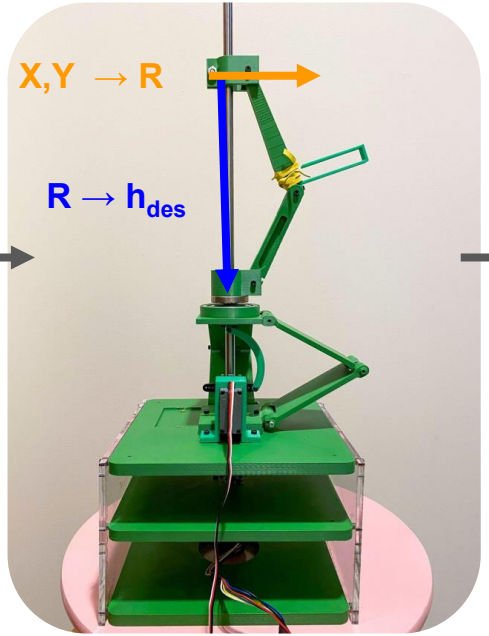
Bearing Position: operate at phase difference of 0 (ideal config)

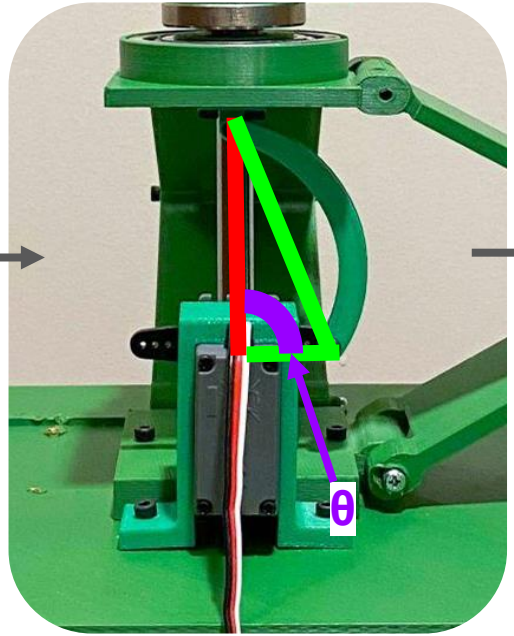
Hardware Controls: Servo



x, y

desired radius from trajectory (x,y)





$$\begin{bmatrix} \frac{\partial x}{\partial \theta} & \frac{\partial y}{\partial \theta} \\ \frac{\partial x}{\partial \phi} & \frac{\partial y}{\partial \phi} \end{bmatrix}$$

inverse kinematics from trajectory

servo angle

Hardware Controls: Motor

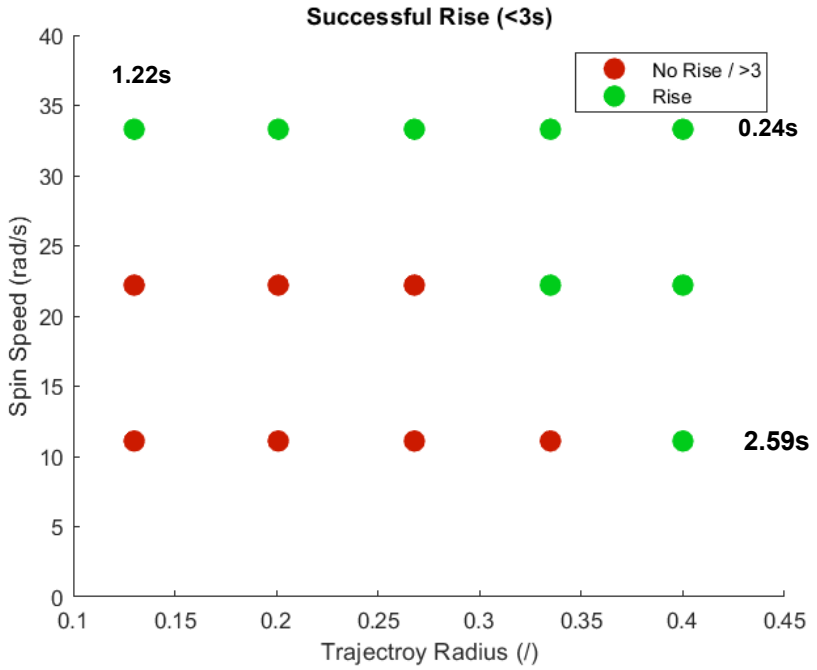
current control with feedforward

$$duty\_cycle = \frac{R * i_{des} + k_t * v + K_p * (i_{des} - i) + K_i * \sum (i_{des} - i)}{voltage}$$

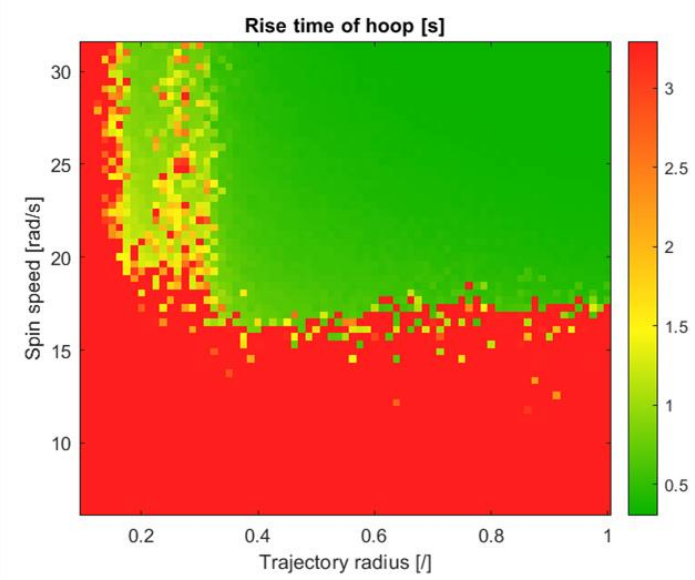
simplified to no feedback + commanded speed

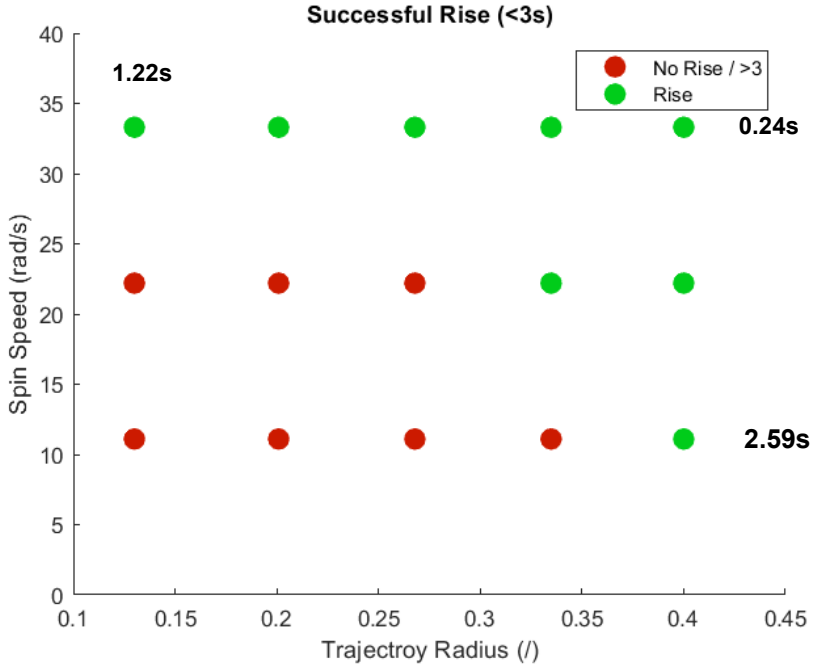
Rise Time Experiment Procedure

1. Pick a trajectory radius
2. Try 3 different duty cycles
3. Note which trials can successfully lift the hoop to level in 3 seconds



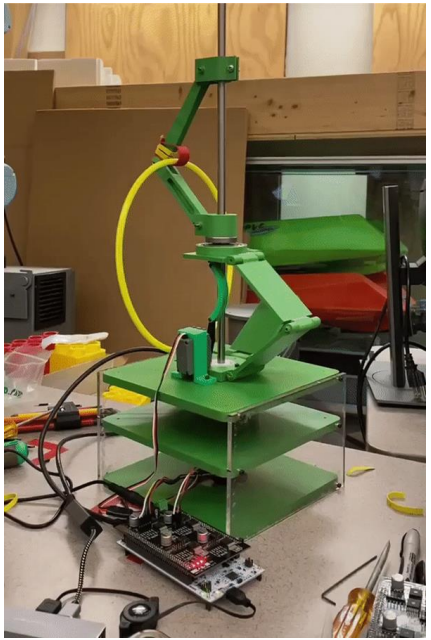
Rise Time Experiment Procedure





Experimental Results

Low Speed
Radius: 0.4
Ang vel (rad/s) : 11.1
Rise time (s) : Inf

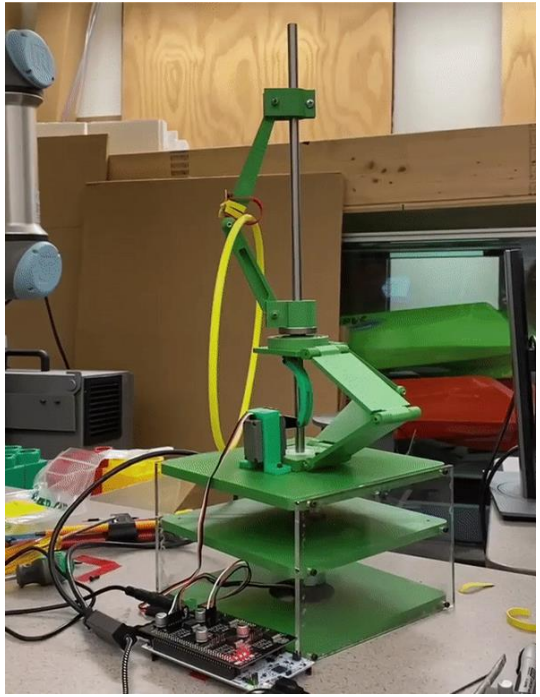


High Speed
Radius: 0.
Ang vel (rad/s): 22.20
Rise time (s): 0.41

Experimental Results

Circular
Radius: 0.22
Ang vel: 22.20

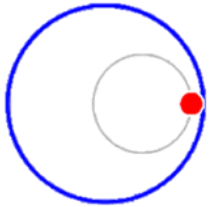
Rise time: 0.65



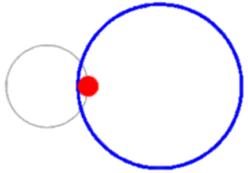
Spiral
Starting Radius: 0.36
Ending Radius: 0.13
Ang vel: 22.20

Rise time: 0.4

Observations Between Different Starting Phase



Hoop is pulled by bearing because of less points of contact



Hoop is rotating about Linkage

Conclusion

	Simulation	Hardware
Increase in radius with increase in speed results in shortest rise times		
Boundary of successful rise time (< 3s) shows decay with an increase in trajectory radius		
Phase difference of 0 is optimal		

What's Next

- Gather more data on trajectory radius and rise time in hardware, this time measuring time values instead of pass fail
- Create 3D Simulation in MATLAB, factoring in gravity
- Improve the accuracy of the robot model
  - Mimic the human waist (rolling contact) in hardware
  - Decrease friction at contact point

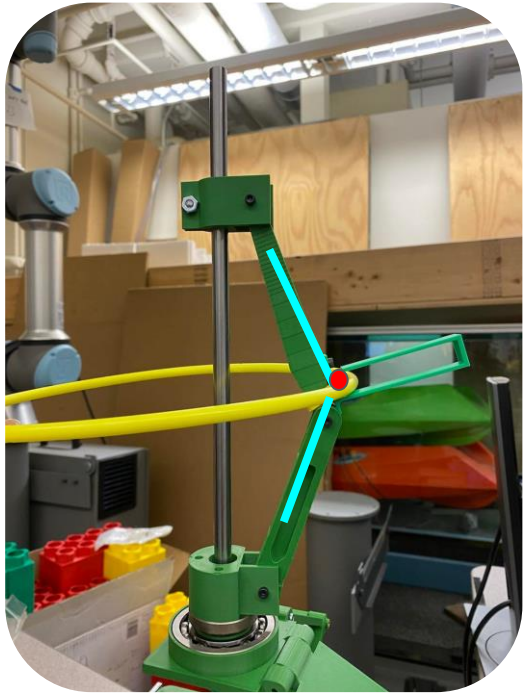
References and Acknowledgements

[1] Cross, R. (2021). Physics of a hula hoop. In Physics Education (Vol. 56, Issue 2, p. 025015). IOP Publishing. https://doi.org/10.1088/1361-6552/abd875

Thank you to Prof. Kim, Andrew, Elijah, Adi, and Se Hwan for guiding us!

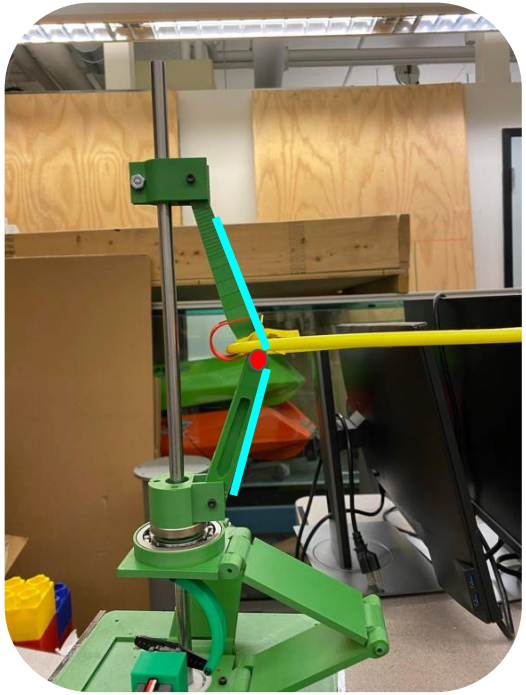
Additional Lessons

Observations: Concavity vs Convexity



Convex Contact was less successful than Concave Contact at lifting the hoop Why?

Hypothesis: Concave contact allows for more surface area in contact, allowing for upwards normal force



Observations: Concavity vs Convexity in Humans

Waist juts in (concave)

Hip juts out (convex)

Where does Hoop naturally Spin? At Waist or Hip?

The WAIST!