Hula Hooping Robot

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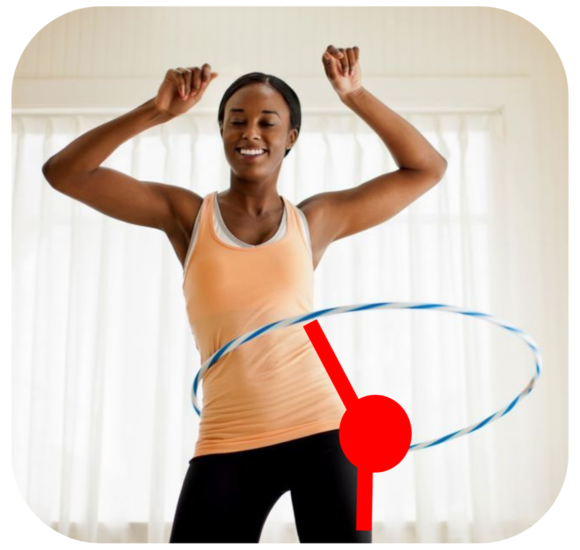
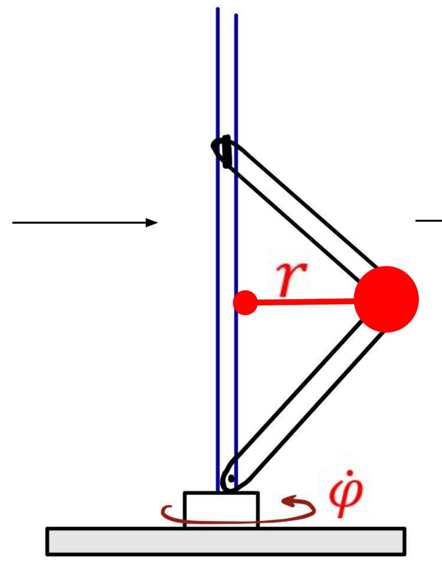
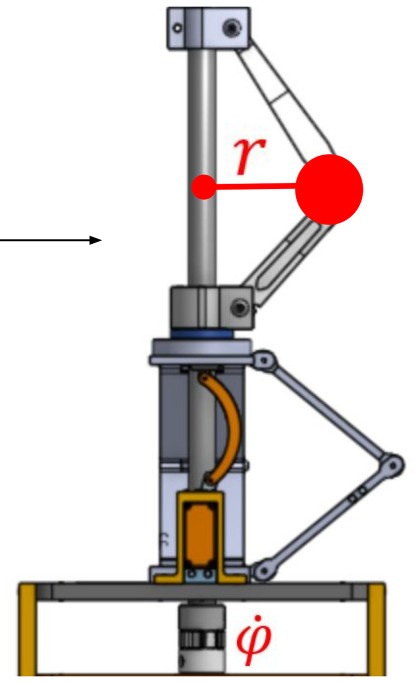
Introduction

What are the principles behind humans hula hooping?


human



2 DOF abstraction



final system

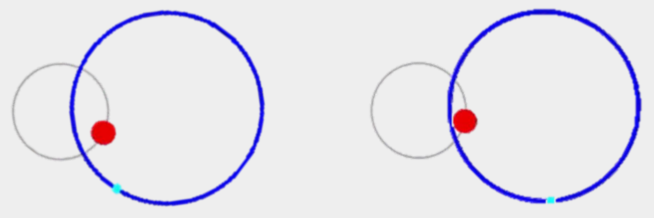
3 inertial coordinates: x, y, φ

2 system parameters: R, $\dot{\varphi}$

How do we minimize *rise time*?

What is the optimal *phase difference*?

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



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

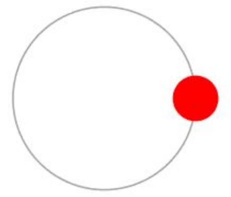
Hypotheses: **Humans use a spiral trajectory which may offer lower rise times. Higher radius and higher speed will generate quicker rise times.**

Simulation Methods

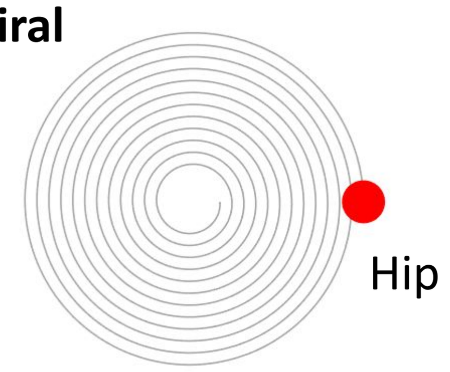
Hip Trajectory → Simulation → Hoop Trajectory

Vary **R** and φ to generate hip trajectories…

Circular



Spiral



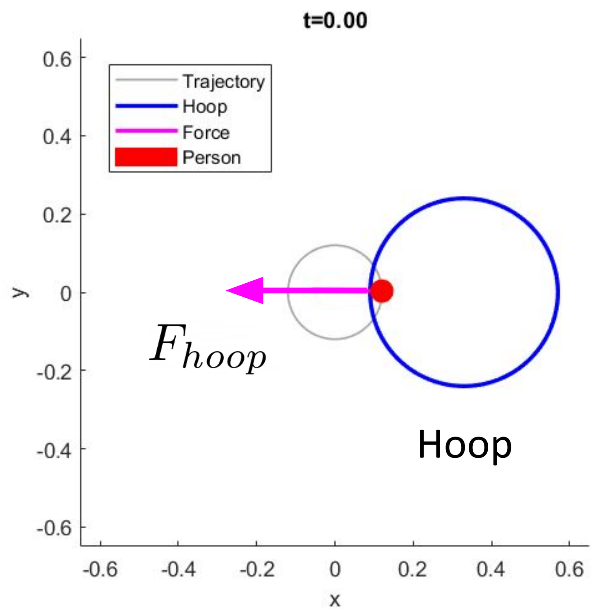
Run forward simulation in MATLAB and apply spring-damper contact dynamics.

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

Apply force onto hoop in normal direction when collision occurs.

Compute **rise time** based on the moving average of contact force.

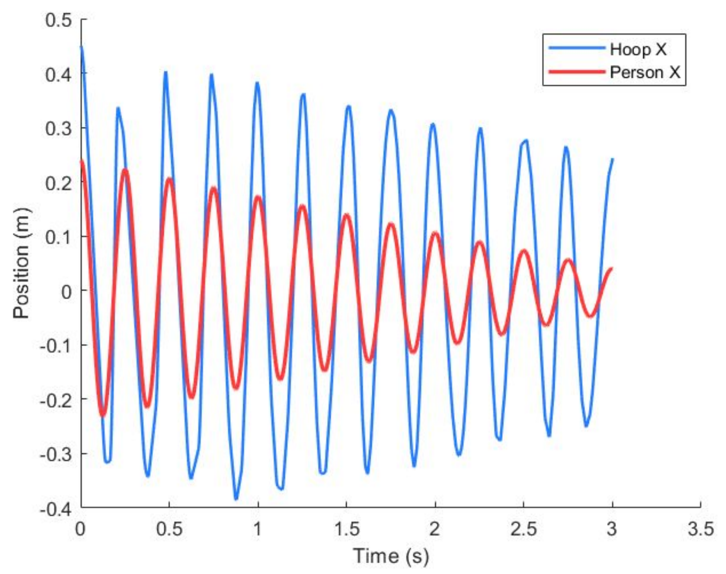
Track effect on hoop trajectory.

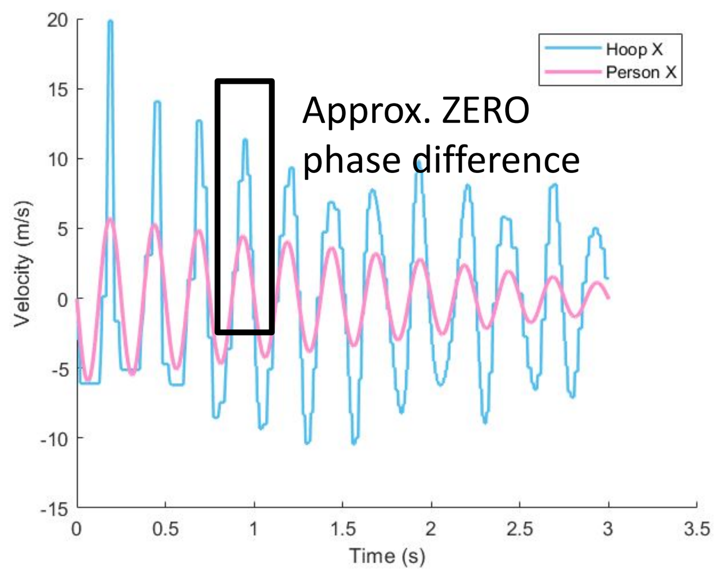


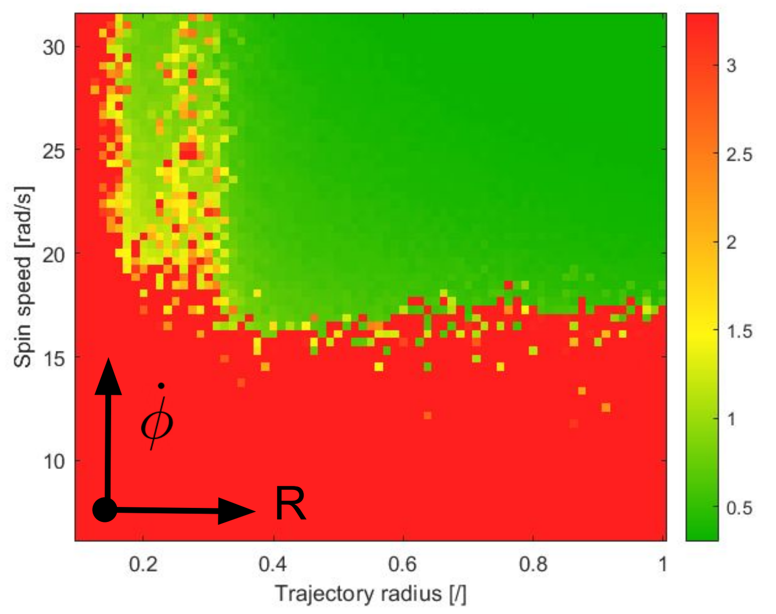
Simulation Results

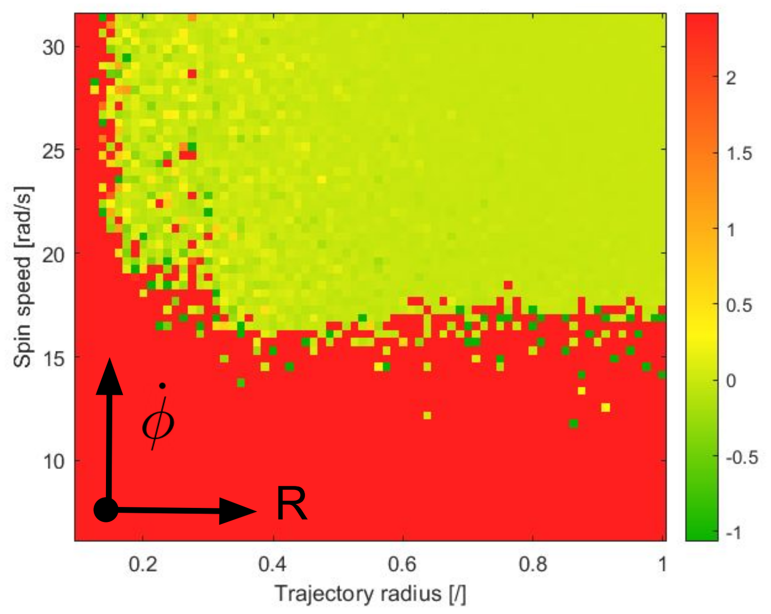
Track hoop movement in simulation to see how it reacts to given hip trajectory.

For given hip trajectory, speed and position of hoop are amplified.





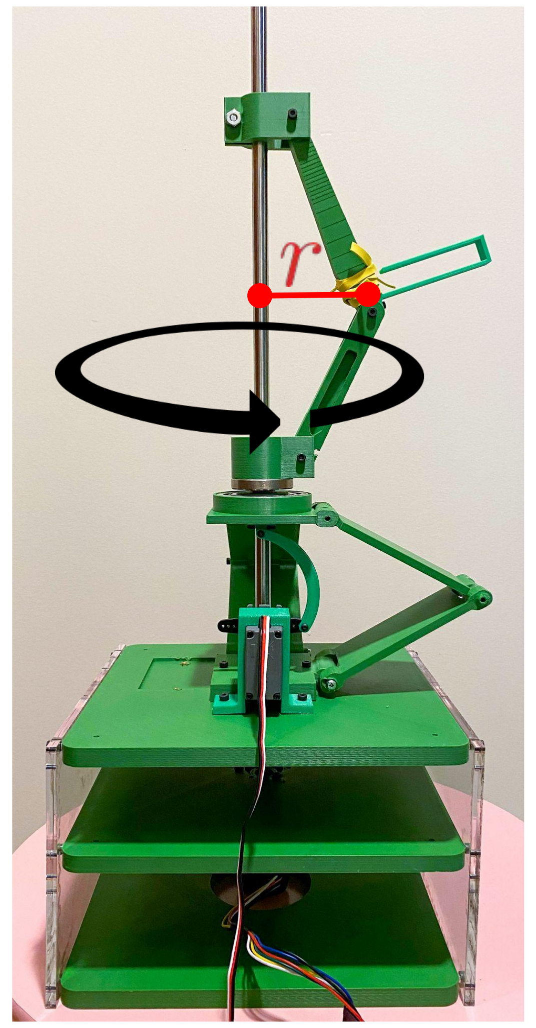




Confirmed that the best trajectories have zero phase difference

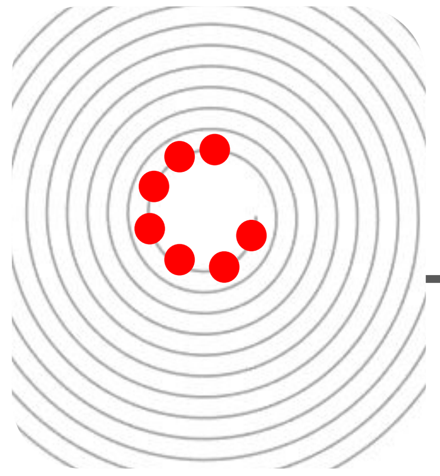
High speed and hip radius give lowest rise time. (maximal contact)

Hardware Design

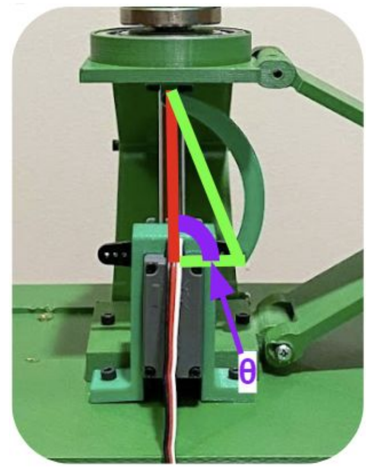


2 DOF system
R - actuated by servo
φ - actuated by motor

servo control


x,y points from trajectory


calculate R and desired height

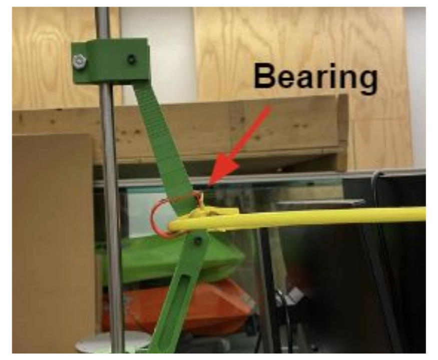

use servo height and servo horn lengths to find theta

motor control

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

→ simplified to no feedback + commanded speed

hoop attachment method



Bearing Purpose:
Constrain the hoop while allowing it to spin

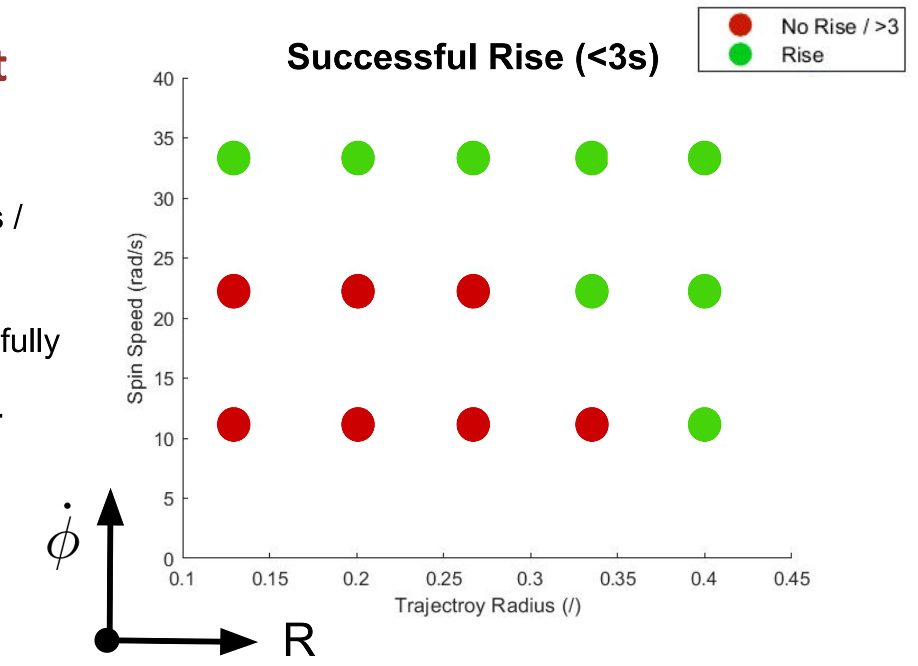
Bearing Position:
Operate at phase difference of 0 (ideal config)

Experimental Results

Measured by analyzing video recording of trial.

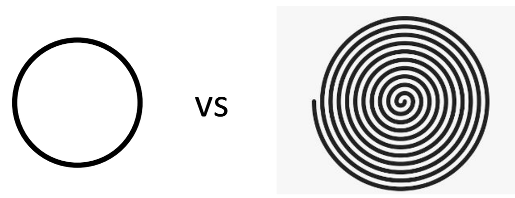
Rise Time Experiment

1. Pick trajectory radius.
2. Try 3 different duty cycles / angular speeds.
3. Note which trials successfully lift the hoop in 3 seconds.
4. Repeat for selected set of radii.



Spiral Rise Time Comparison

Ran two trials at the same speed for a spiral vs a circle at the middle spiral radius



Trajectory	Radius	Speed	Rise Time
Circle	0.3	11.1	Inf
CIrcle	0.3	22.1	0.65
Spiral	0.4 ->0.2	22.1	0.4

Conclusions

	Simulation	Hardware
Higher radius, higher speed gives minimum rise time to steady state.	✓	✓
Phase difference of 0 is optimal.	✓	?
Spiral hip trajectory gives lower rise time than circular trajectory.	✓	✓

Future Work

- 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

[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

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