UROP Final Presentation

-Developing Origami robot simulator using Pybullet library-

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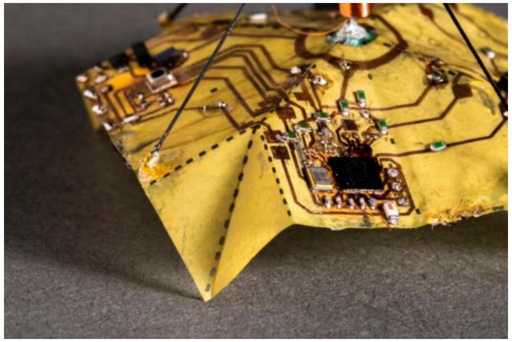
SNU STAR LAB, December 14th 2023

Contents

Research Purpose

- Research Objectives
  - Developing Origami Robot Simulator using Pybullet
  - Imitate **Drop Test**
  - Test Origami Robot **Control**



- Significance of the Study
  - Control of Origami Robot is challenging
  - Bistability, Light-weight, Deformability, Grasping Motion
  - Control Method Research needed

- Originality of the Study
  - Complicated constraints between panels: New Simulation System Needed
  - No Study about Origami robot simulation on drop test, control simulation

- Expected Contribution
  - Opening a new Methodology of Origami Robot Research
  - Optimize Design for Drop Test
  - Control of Origami Robot: Microfliers, Jumping Motion

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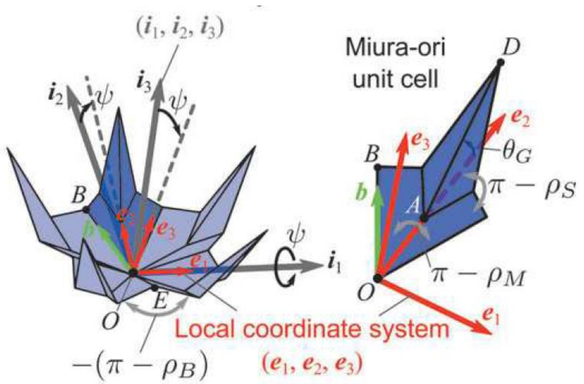
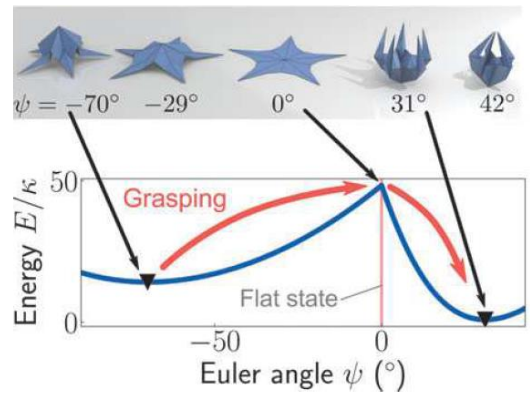
Prior Research: Origami Robot Kinematics / Drop Test

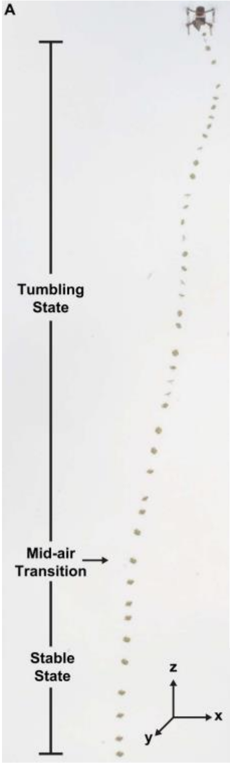
- ‘Leaf-Like Origami with Bistability for Self-Adaptive Grasping Motions’ (Yasuda & Yang, 2022)
  - Analysis of Origami Robot Kinematics
    - Describe configuration using 1 variable ψ (parameters ρ_M, ρ_B, θ_G)
  - Bistability of Origami Robot
  - Drop Test

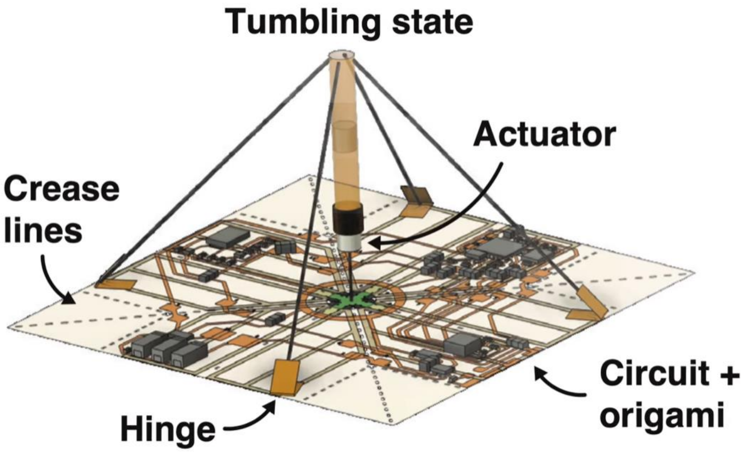


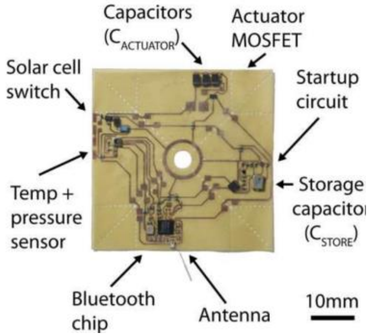


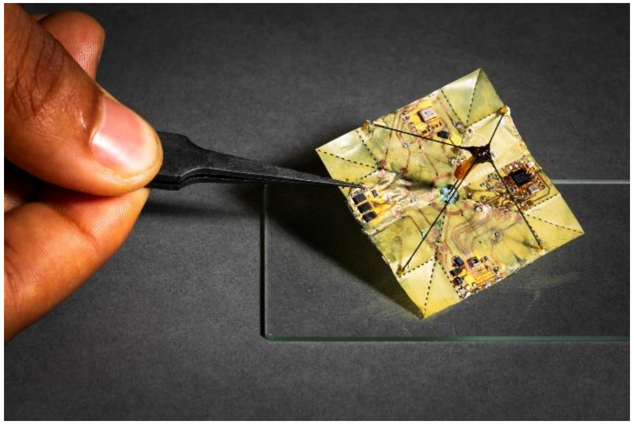
Prior Research: Fabrication of controllable Origami Robot

- ‘Solar-powered shape-changing origami microfliers’ (Johnson, 2023)
  - Fabrication of controllable Origami Robot
    - Costly, or at least Complicated: Necessity for control simulation
  - Control configuration mid-air, falling motion



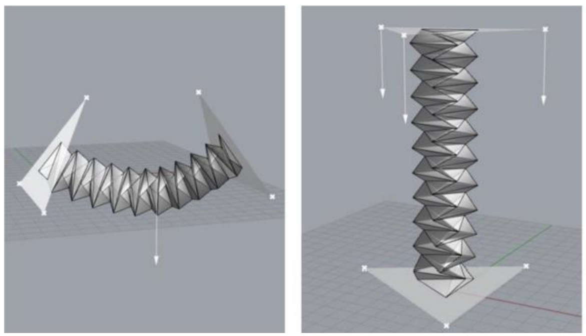


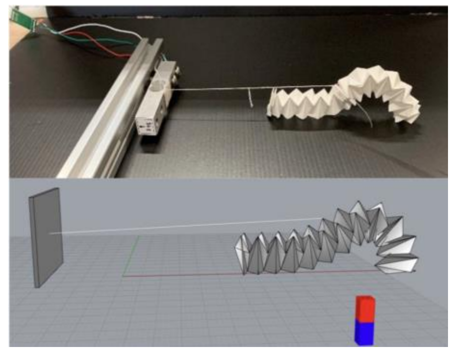




Prior Research: Simulation research on Origami Robot

- ‘Lattice-and-Plate Model: Mechanics Modeling of Physical Origami Robots’ (Zhang, 2023)
  - Simulate Origami robots using lattice-and-plate model, **based on mechanics**
- ‘Multiphysics Simulation of Magnetically Actuated Robotic Origami Worms’ (Swaminathan, 2021)
  - Simulate magnetically actuated Origami robots using **Grasshopper 3D** to calculate **force, strain**

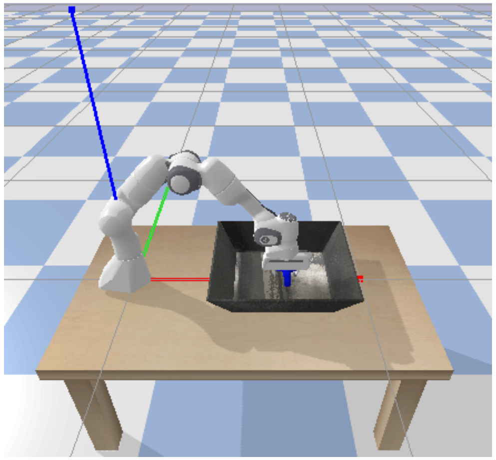


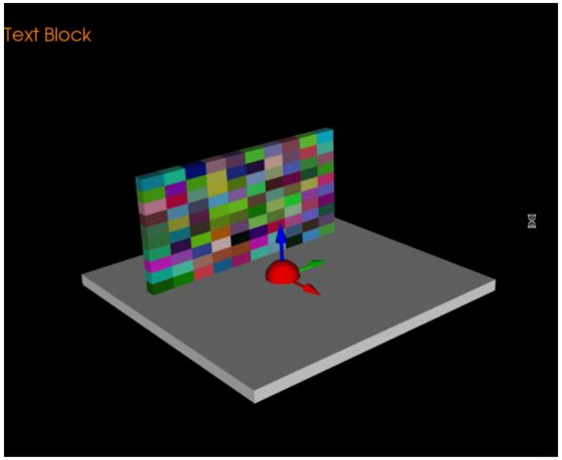


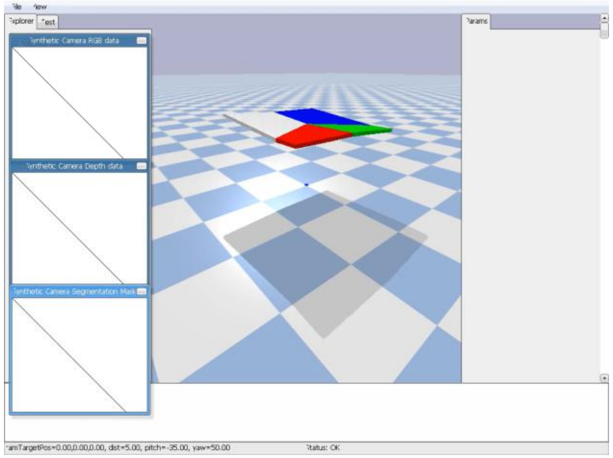
- ‘Modeling of an origami robot driven by electrostatic forces’ (Li, 2021)
  - Simulate origami robot using **FEM**
- ‘Finite element simulation of robotic origami folding’ (Thai, 2018)
  - Simulate origami robot using **FEM**

=> No Simulation base research about **control / drop test, dynamics**

- **Pybullet**: Open-source Python library for simulating & controlling physics in 3D environments.
- Example: Simulation for dropping 4-Panel Origami Robot

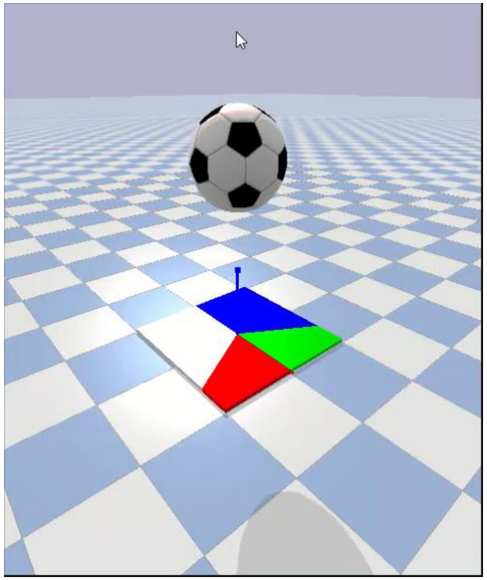


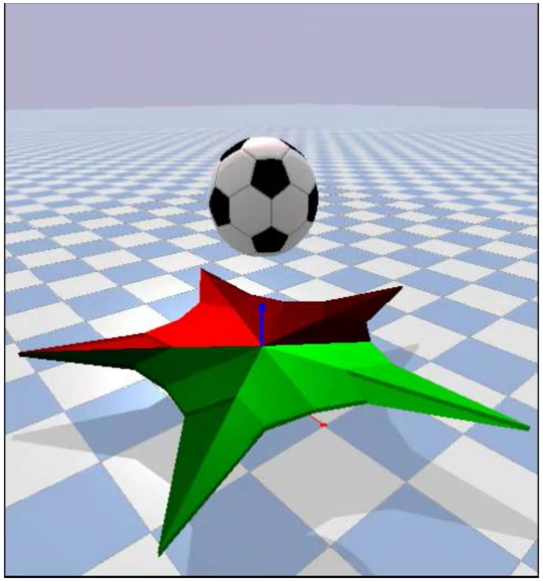




Research Progress: Review of Midterm Presentation

- Simulation goal: Recreate the Drop test from 'Leaf-Like Origami with Bistability for Self-Adaptive Grasping Motions'(Yasuda & Yang, 2022)
- Setup drop test simulation environment: Adjust COR (Coefficient of Restitution), Add sphere
- Fabricated five Miura-Ori unit cells with appropriate Geometry
- Calculated configuration with respect to ψ using nonlinear solver
    - **Failed to implement in pybullet**





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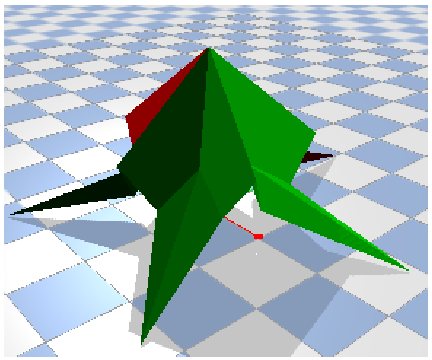
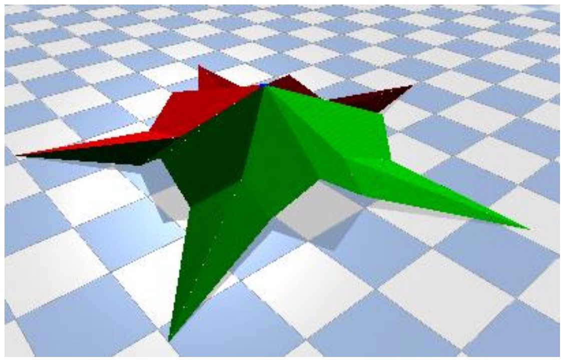
Research Progress: Analysis of Origami robot's mechanism

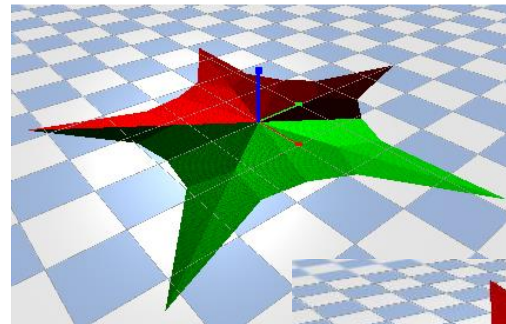
- Succeed to implement various configuration in pybullet
  - Revised panel making algorithm using vector calculation



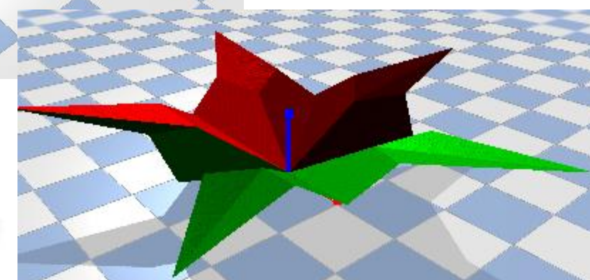
$\psi = -70°$



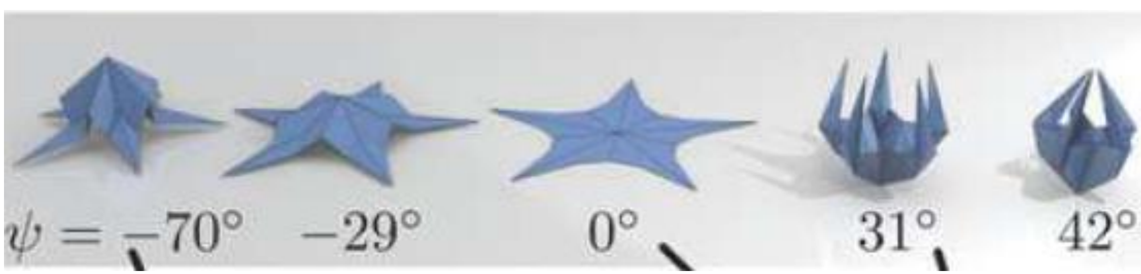
$\psi = -29°$

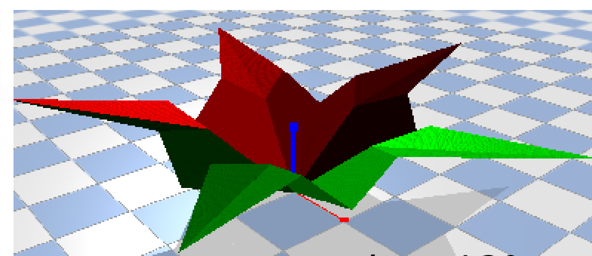


$\psi = 0°$



$\psi = 31°$





$\psi = 42°$

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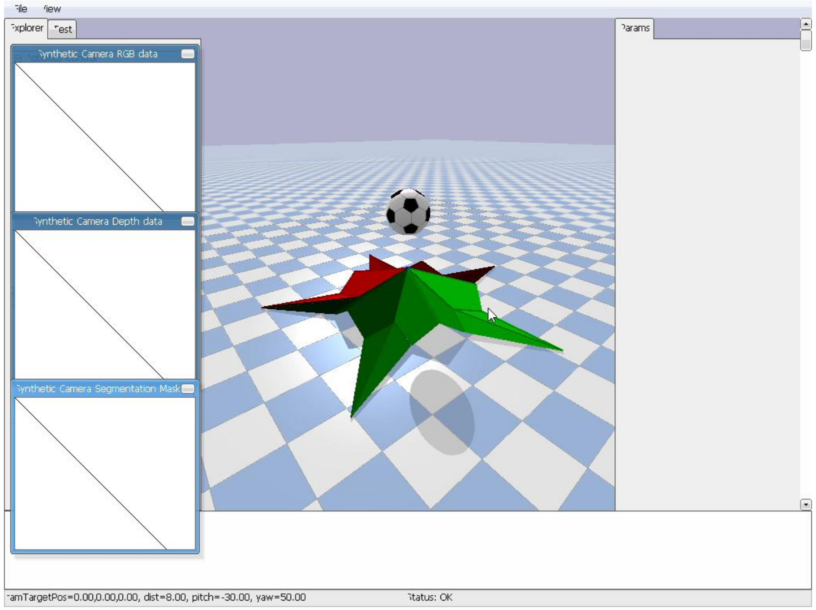
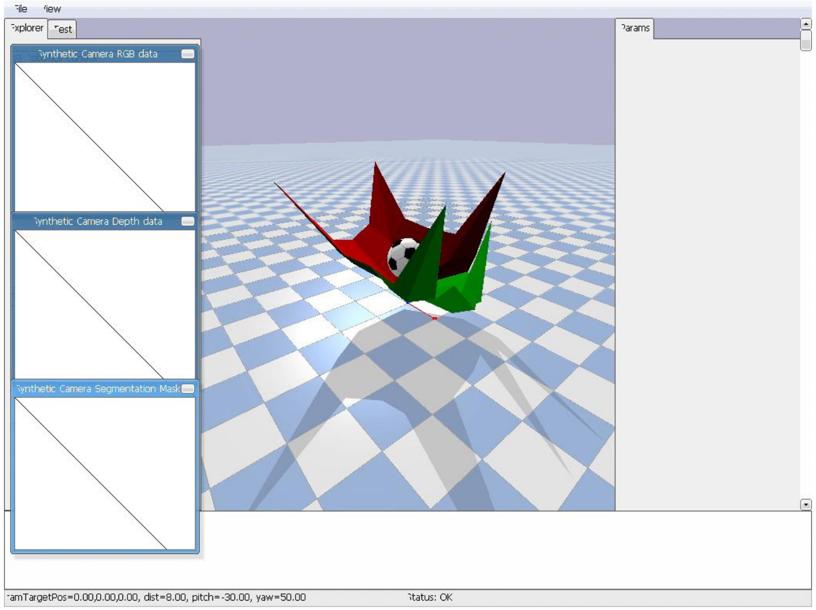
Research Progress: Drop Test

- **Succeed** to imitate drop test in pybullet
  - Thickness of the Panels is crucial to trigger grasping motions



Thickness = 0.05

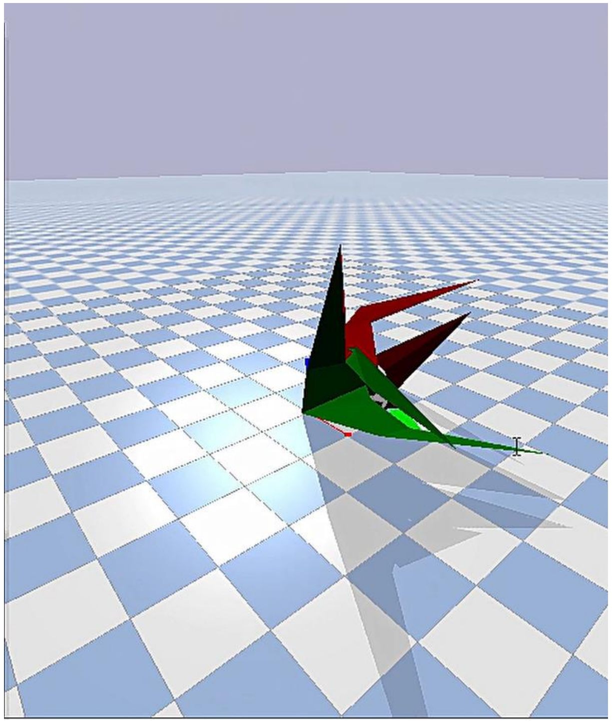


Thickness = 0.0001

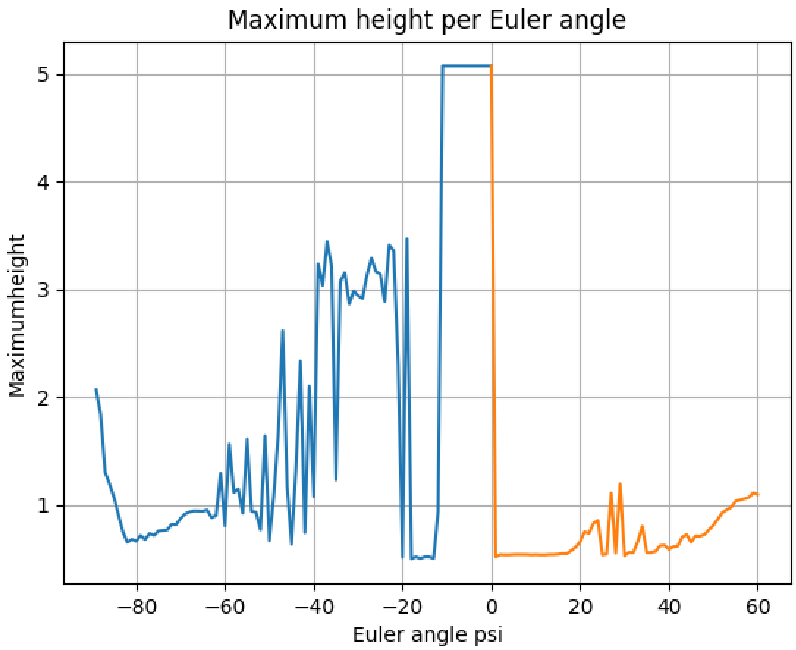
Grasping motion occurs

Research Progress: Drop Test

- Optimize grasping motion
  - Obtain optimal initial configuration, geometric condition for optimal grasping motion **by simulation**
  - Optimal: Minimize the maximum bouncing back height



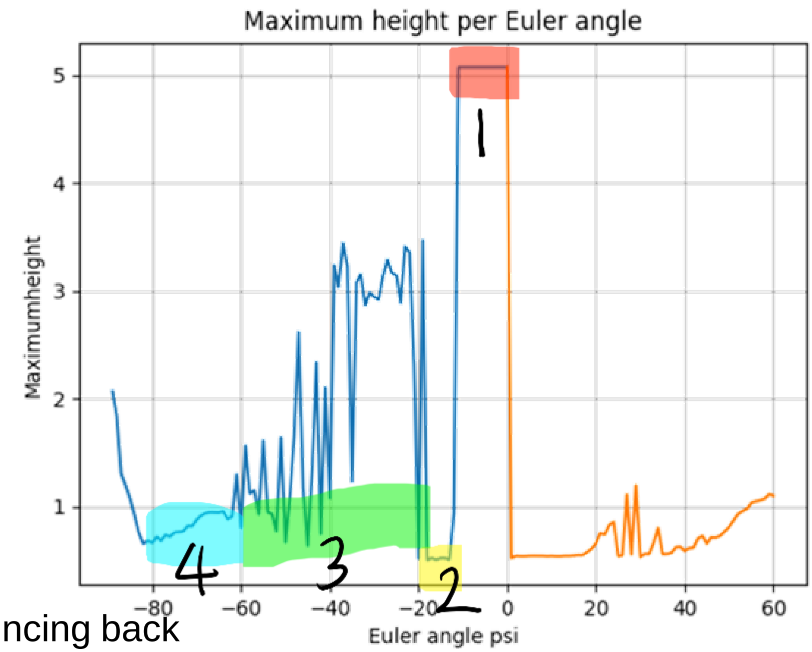
$(speed \times 100)$

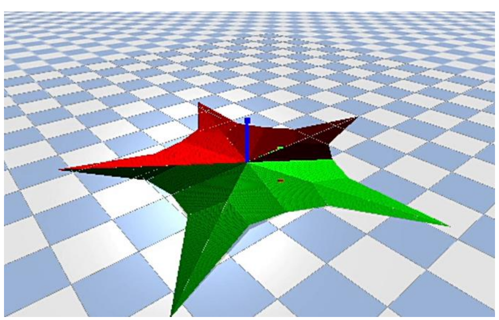


Geometric Contraint: $\overline{OA} = 30, \overline{AD} = 50$

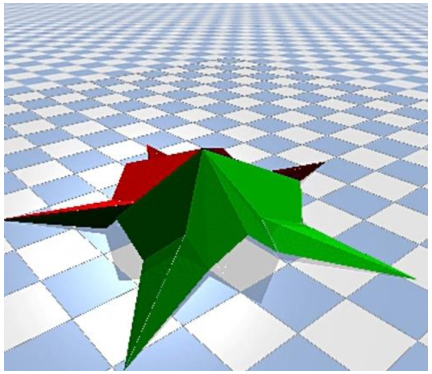
Research Progress: Drop Test

- Interpretation of the simulation results
- Zone 1
  - Panels could not withstand the gravity
  - Every Origami robot act like $\psi = 0$
- Zone 2
  - The ball doesn't bounce back (probably error)
- Zone 3
  - Grasping motion occurs, along with unstable bouncing back
- Zone 4
  - Stable grasping motion

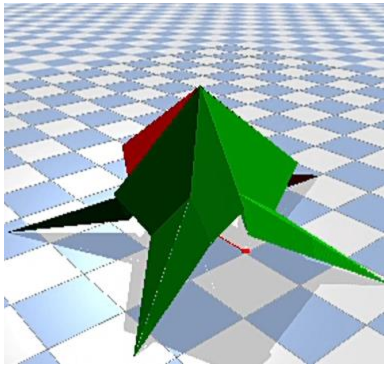




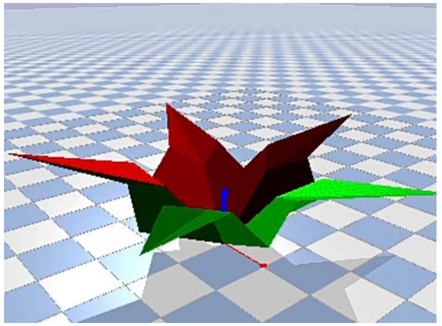
Zone 2



Zone 3



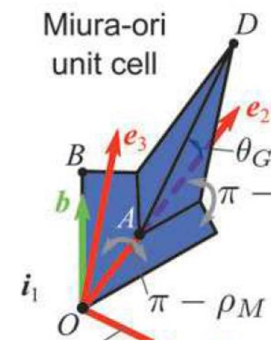
Zone 4

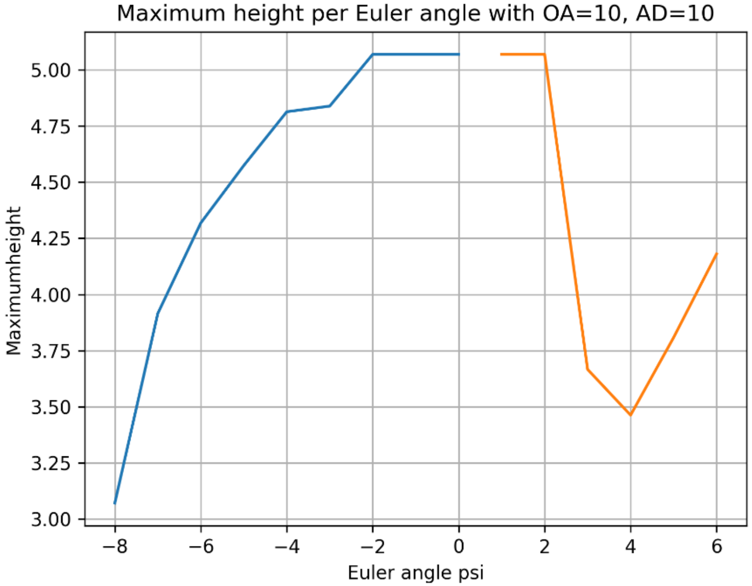


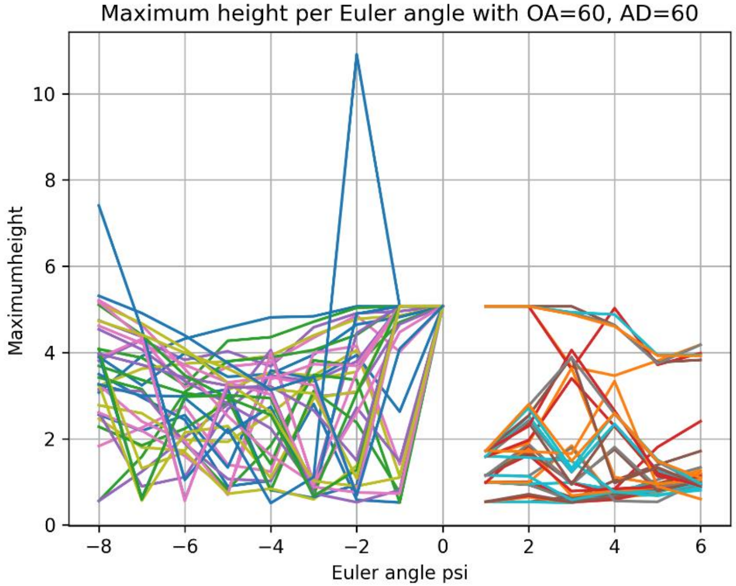
Positive ψ

Research Progress: Drop Test

- Similar simulation experiments based on geometric constraints
- Experiment with $\overline{OA}$, $\overline{AD}$ = 10 ~ 60



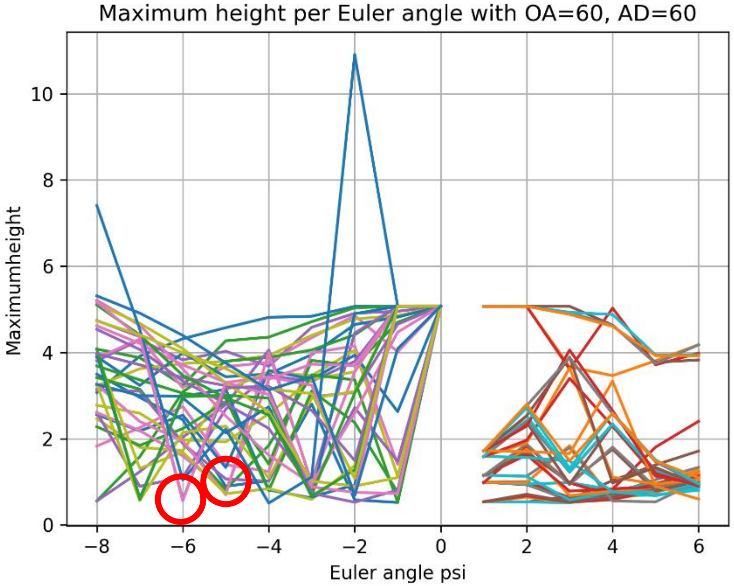


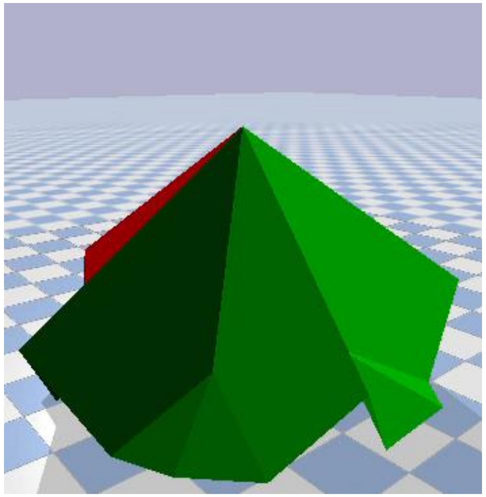


=> Using pybullet simulation, able to obtain optimal condition for grasping

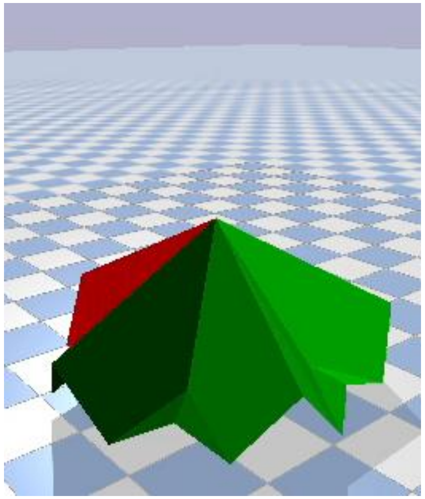
Research Progress: Drop Test

- Sometimes we get the expected motion, sometimes we don't
- 2 Optimal-looking solutions for drop test: $(\overline{OA},\ \overline{AD}, \psi) = (60, 30, -60°),\ (40, 10, -50°)$





$(\overline{OA}, \overline{AD}, \psi) = (60, 30, -60°)$
Not grasping motion



$(\overline{OA}, \overline{AD}, \psi) = (40, 10, -50°)$
Grasping motion

- Low height because of damping effect, rather than grasping motion
- Need Better Experiment Setting

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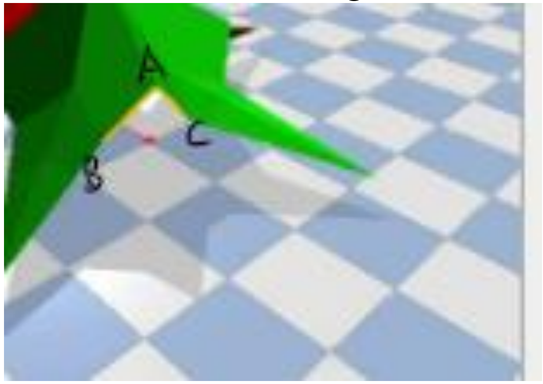
Research Progress: Control of Origami Robot

- To control Origami Robot, Joint attachment is needed
- Need to revise URDF(Unified Robot Description Format) File
- Now Working on..

- Goal: To attach joints between Origami Panels and control
- Apply to Four Miura-Ori unit cells and implement back-and-forth, left-and-right motion



=> For Future Works

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Future Work

- Find the optimal condition for grasping motion (if necessary)
  - This project aimed to see possibility of pybullet
- Control the Origami robot by attaching joints
  - Revise URDF File
  - Implement Jumping motion & back-and-forth, left-and-right motion
  - Apply Reinforcement Learning

Appendix References

[1] Yasuda, H., Johnson, K., Arroyos, V., Yamaguchi, K., Raney, J. R., & Yang, J. (2022). Leaf-like origami with bistability for self-adaptive grasping motions. Soft Robotics, 9(5), 938-947.

[2] Johnson, K., Arroyos, V., Ferran, A., Villanueva, R., Yin, D., Elberier, T., ... & Gollakota, S. (2023). Solar-powered shape-changing origami microfliers. *Science Robotics*, *8*(82), eadg4276.

[3] Zhang, H., & Paik, J. (2023). Lattice-and-plate model: Mechanics modeling of physical origami robots. *Soft Robotics*, *10*(1), 149-158.

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[5] Li, J., Godaba, H., Zhang, Z., Foo, C. C., & Zhu, J. (2021, November). Modeling of an origami robot driven by electrostatic forces. In *2021 27th International Conference on Mechatronics and Machine Vision in Practice (M2VIP)* (pp. 651-655). IEEE.

[6] Thai, P. T., Savchenko, M., & Hagiwara, I. (2018). Finite element simulation of robotic origami folding. *Simulation Modelling Practice and Theory*, *84*, 251-267.

FAQ

Thank you for your time and attention.