SOFT ORIGAMI INSPIRED 3D PRINT-IN-PLACE ARTIFICIAL INTELLIGENCE ROBOTS

Saan Cern Yong & Sheng Ze Yeoh

Introduction

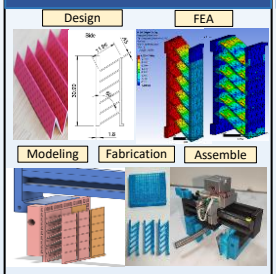
During Covid-19 pandemic, the food industry faced challenges in food handling to avoid contamination and thus required more automation using soft robotics.

Problem: Current soft robots require cast molding, high assemble time and effort, large actuators using pneumatic, or fluid-driven origami inspired artificial muscles and upfront actuation awareness due to absence of artificial intelligence.

Challenges and Constraints: Conventional rigid robots need different rigid grippers to cater for known grasping objects and situation. Modular origami gripper requires folding of multiple rigid sheets, meticulous folding skill set and effort.

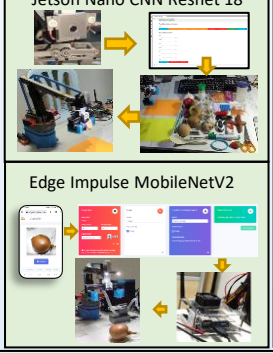
Project Design – Materials & Methods

Soft Origami Zigzag Gripper

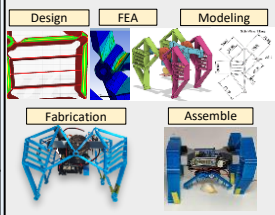


- 3D print-in-place using soft TPU filament
- 60-degree slant allows flexure hinge movement

AI Object Classification



3D Print-in-place Soft Origami Legged Robot (3DSOLR)



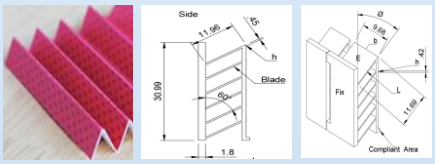
- Theo Jansen's leg design
- Novel 3D print-in-place linkage gait legs using TPU
- Made with 10 origami flexure joints with thin area 0.4mm

Engineering Objectives: To develop 3D print-in-place easy assembled under-actuated soft origami inspired grippers and a legged robot with artificial intelligence capability to grasp various kinds of objects with high repeatability under different conditions and mobility.

Observations

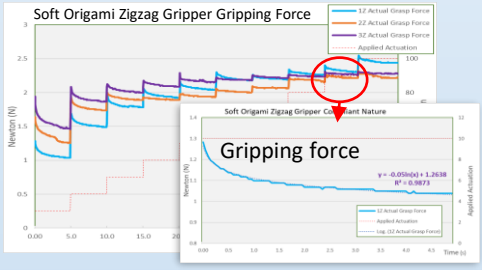
Soft Origami Zigzag Gripper - Grasping Performance

Topology –Parallel thin zigzag blades
Geometry - Ø, 60^0 for guided buckling
Material – TPU with flexure joint

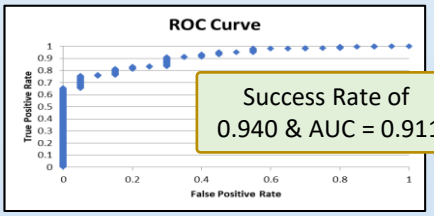


Compliance energy exerted to object:

$$= \int_0^x \frac{Ebh^3}{4L^3}(z)\sin\emptyset\, dx$$



- Soft origami zigzag gripper has **compliant** effect
- Logarithmic decaying grasp force of (**-0.05ln(x)**) with **0.9873 R^2**



Success Rate of 0.940 & AUC = 0.911

Logistic model for grasping performance:

$$ln\left(\frac{\hat{p}}{1-\hat{p}}\right) = -0.308 + 0.210S + 0.119F - 0.058W$$

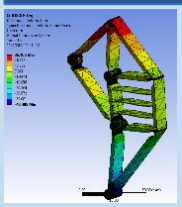
$\hat{p}$ is the probability of grasping successfully ;
S = Speed ; F = Gripping force ; W = Object weight

AI Object Classification

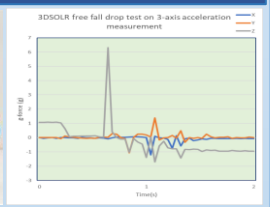
Neural Network	Accuracy	F1 Score
CNN Resnet 18	0.923	0.956
Mobile Net V2	0.907	0.908

ANOVA showed the mean of object classifications are not equal, with the *p*-value 9.36E-72 < 0.05.

3D Print-in-place Soft Origami Legged Robot



- Lower **deceleration** & longer duration
- **Rebound** & **compliant** behaviour
- **Regains original** leg shape and survives multiple drop tests



Results & Conclusions

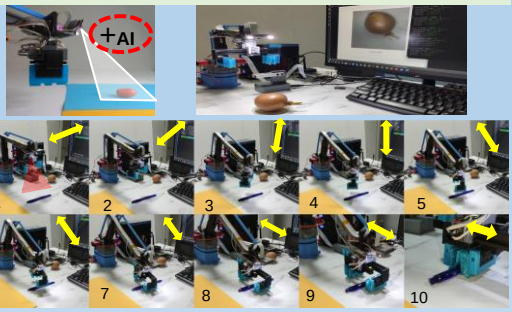
Soft Origami Zigzag Gripper

- **3D print-in-place** using **TPU** with minimal assemble time
- Exhibited under-actuated effect
- Achieved an **accuracy of 0.940 and AUC=0.911** in logistic model
- Gripping force, speed & object weight affected grasping performance
- Experimental results collected from 300 data on 10 objects, showed that soft origami zigzag gripper performed better than hard gripper using paired *t*-test

Grasping Performance	Mean	Variance
Soft origami zigzag gripper	0.9333	0.0624
Hard gripper	0.7667	0.1795

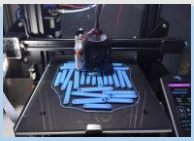
AI Object Classification

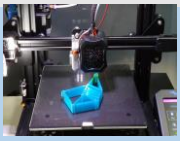
- Multiple data acquisition sourced at least 450 images from Jetson Nano camera and Smartphone on 10 objects
- Trained object classification in the Edge Impulse MobileNetV2 cloud and deployed the neural network model EIM into Jetson Nano
- Optimizing robot grasping by adjusting the gripping force and robot arm speed based on the object characteristics upon classification for upfront actuator awareness



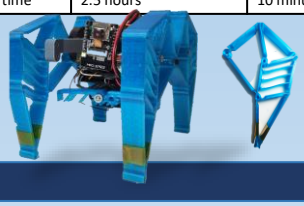
3D Print-in-place Soft Origami Legged Robot

- Successfully **3D print-in-place** soft origami legged robot
- **Less** assemble time and effort
- Enhanced with AI MobileNetV1
- **Regains** shape, **compliant and no backlash** on flexure hinge





	Rigid Legged Robot	3DSOLR
Printing times	10 min x 40 (PLA)	4hr x 4 (TPU)
Leg parts	10 links x 28 bolts	4 legs x 2 bolts
Assembly effort	10x28 = 280 points	4x10 = 40 points
Installation time	2.5 hours	10 minutes



Future Applications

Applications in the food industry automation to overcome pandemic challenges:

- Soft origami zigzag gripper enhanced with object classification - Food handling, labour shortages
- 3D print-in-place soft origami legged robot – Inspection, delivery, monitoring