Soft End-Effectors and Their Applications

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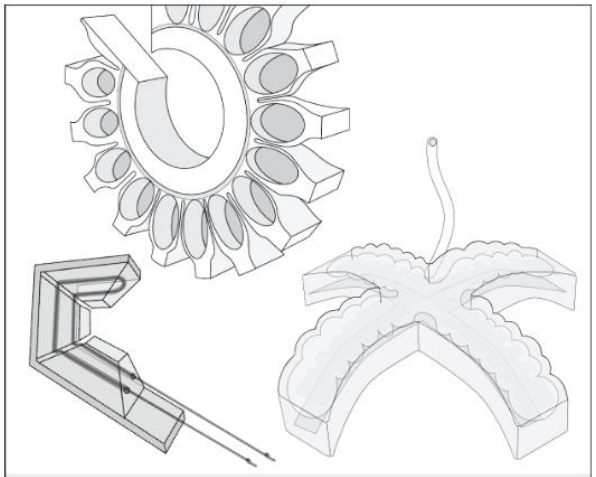
Agenda

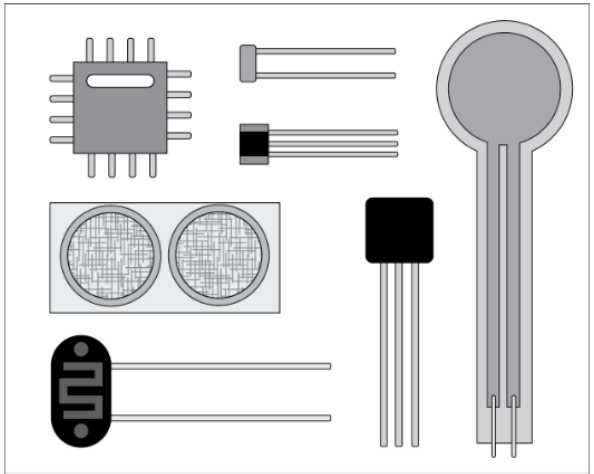
- What is robotic end-effector?
- Why soft robotic end-effectors are important?
- What are the existing soft robotic end-effectors?
- How to make soft robotic end-effectors?
- How to model and simulate soft robotic end-effectors?
- What are the potential applications of soft robotic end-effectors?
- Soft robotic end-effectors developed by our group
- Future research directions
- Report

Learning Resources

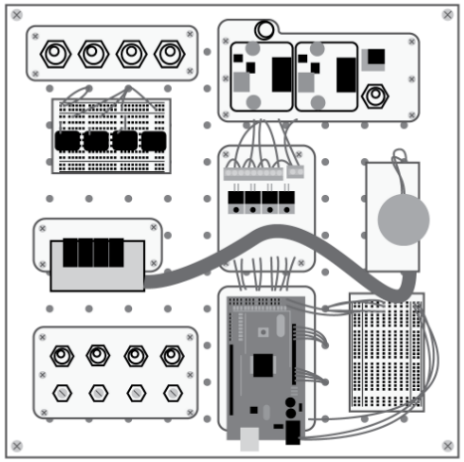
soft robotics toolkit



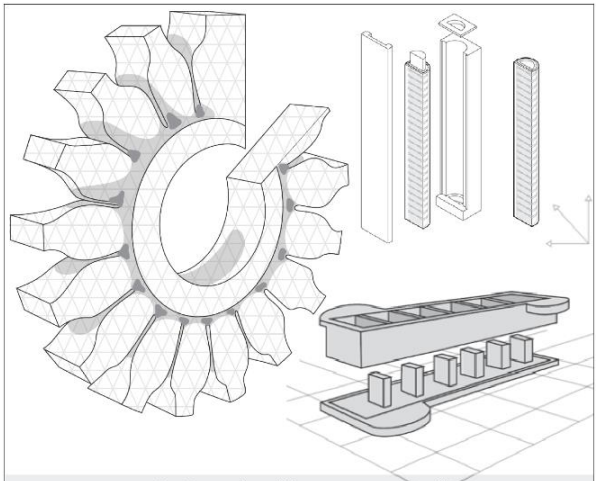
Actuators



Sensors



Controls



Modeling and Manufacturing

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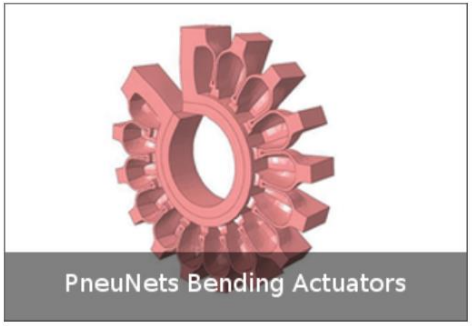
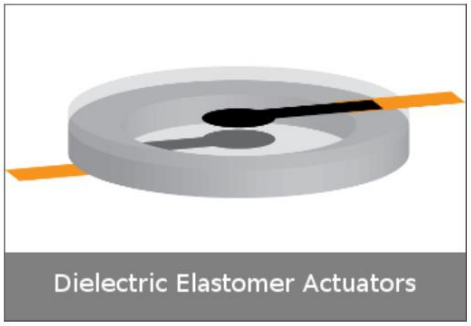
Soft Robotics Toolkit---Actuator


PneuNets Bending Actuators

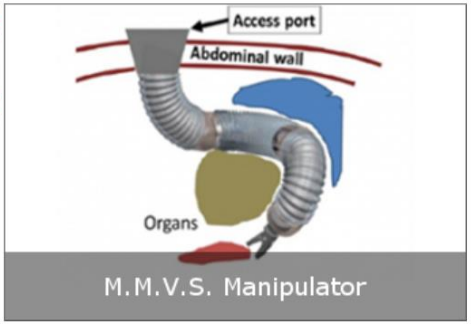

Fiber-Reinforced Actuators


Dielectric Elastomer Actuators

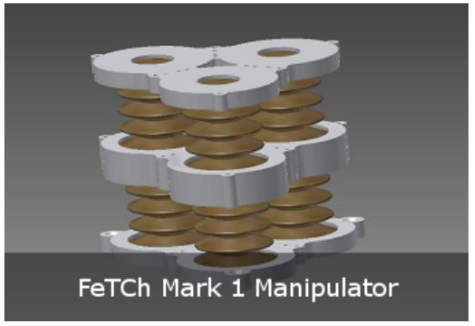

Combustion-Driven Actuators


Pneumatic Artificial Muscles

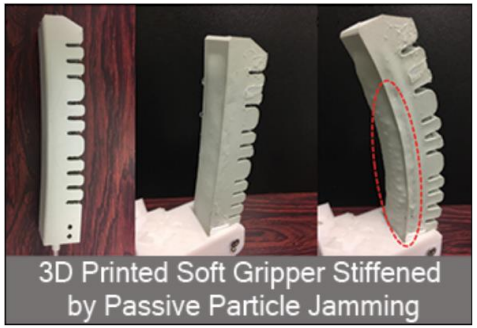

SDM Fingers

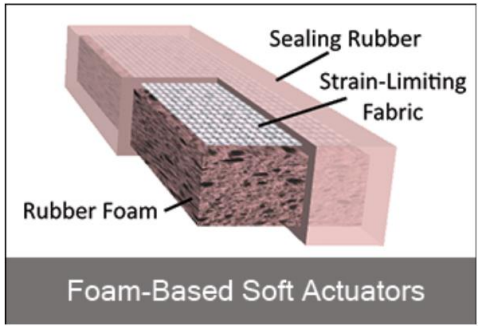


M.M.V.S. Manipulator

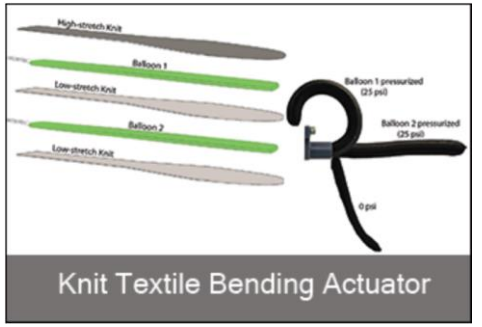

FeTCh Mark 1 Manipulator


HPN Manipulator


3D Printed Soft Gripper Stiffened by Passive Particle Jamming



Foam-Based Soft Actuators


Knit Textile Bending Actuator

What Are Potential Applications?

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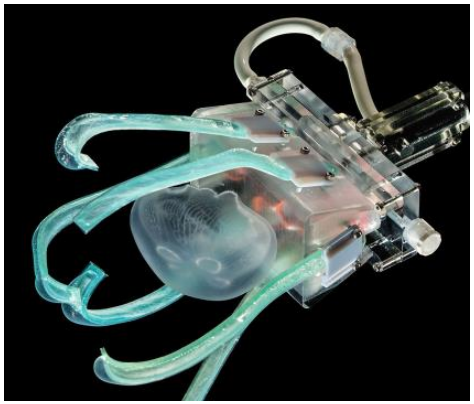
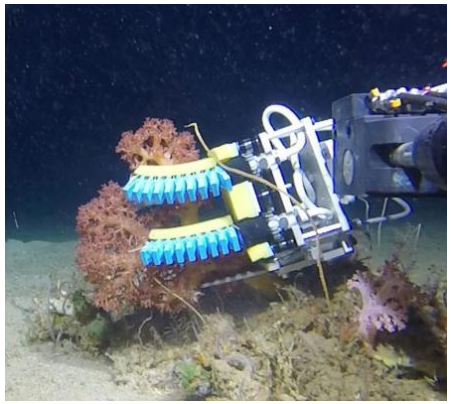
Food industry

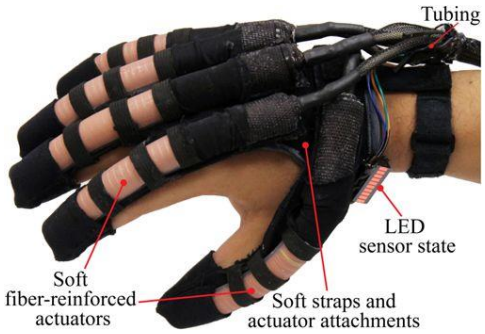
Agriculture and Fishery

Living creature grasping





Biomedical application



Applications that We are working on

Automation Challenges

① Grasping

1. Too many categories
2. Large differences
3. Complex properties
4. Soft and fragile

② Recognition

Random picking scenario

③ Application

1. Food compatibility
2. High speed motion
3. Durability
4. Contamination
5. Sterilization
6. Ease of use

④ Cost

Hardware	Software	SI
	Recognition Machine learning Image processing Conveyor tracking	System Integration Maintenance

SIP Project (2018-2022)

Cross-Ministerial Strategic Innovation Promotion Program

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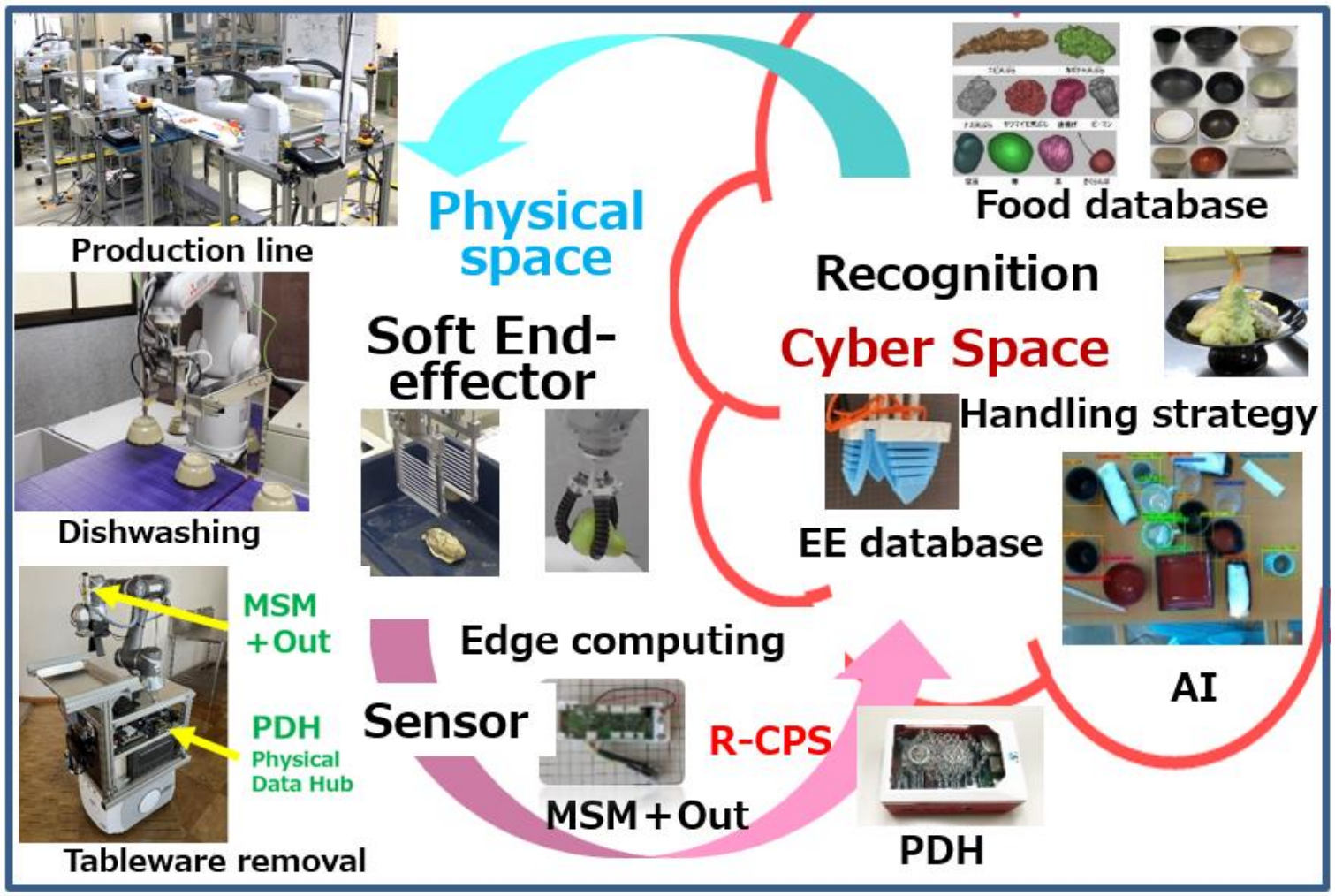
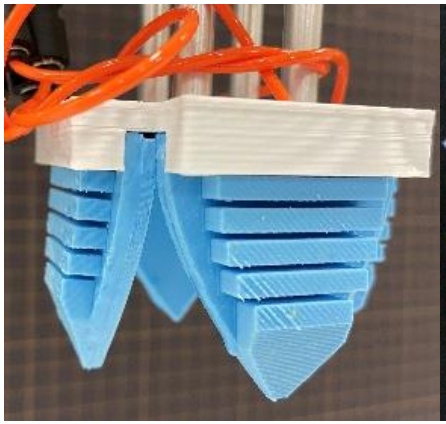
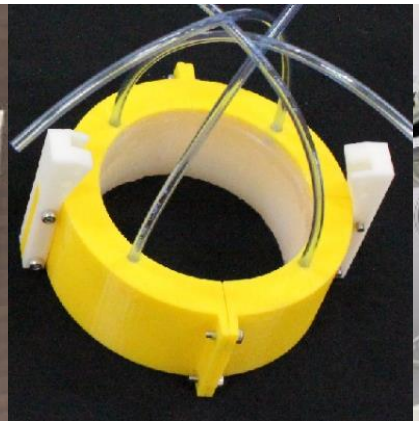
Title: Soft End-Effector System (SSES) for Cyber Physical System (CPS) Construction



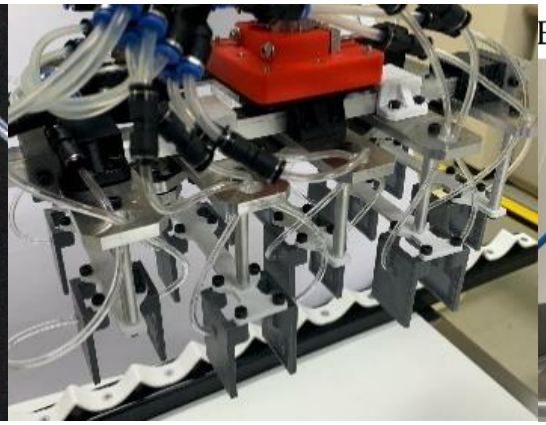
Our developed soft robotic EEs



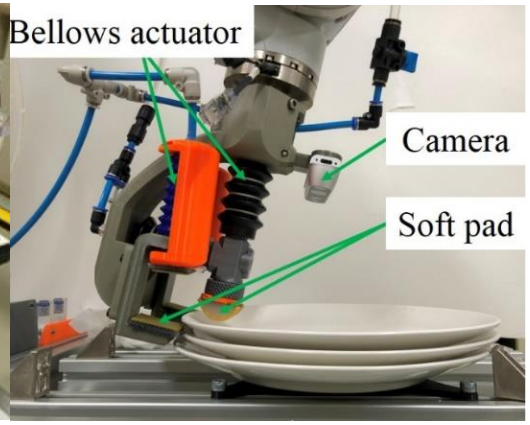
Wrapping gripper



Circular shell gripper

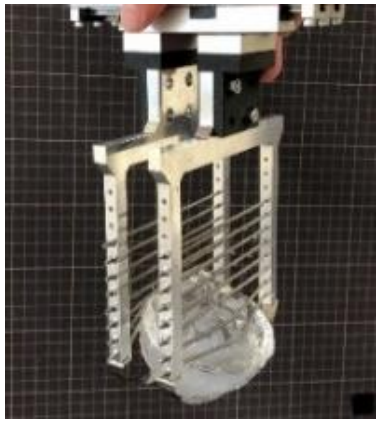


Parallel shell gripper

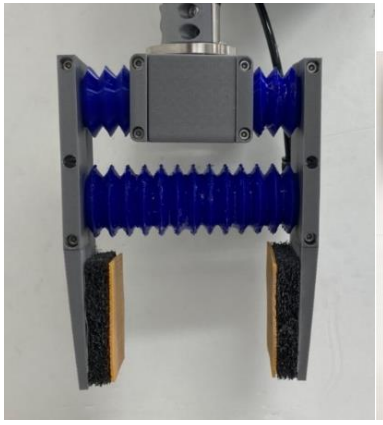


Dishwashing hand

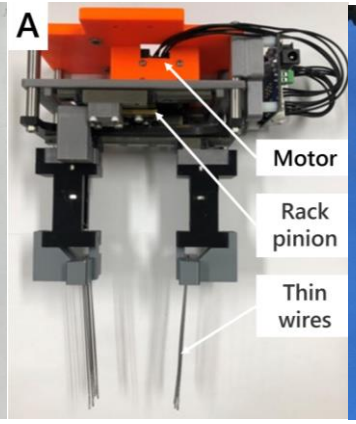
Needle gripper



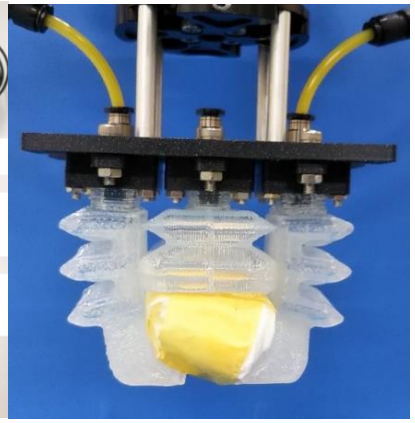
Scooping-binding gripper



Bellows gripper

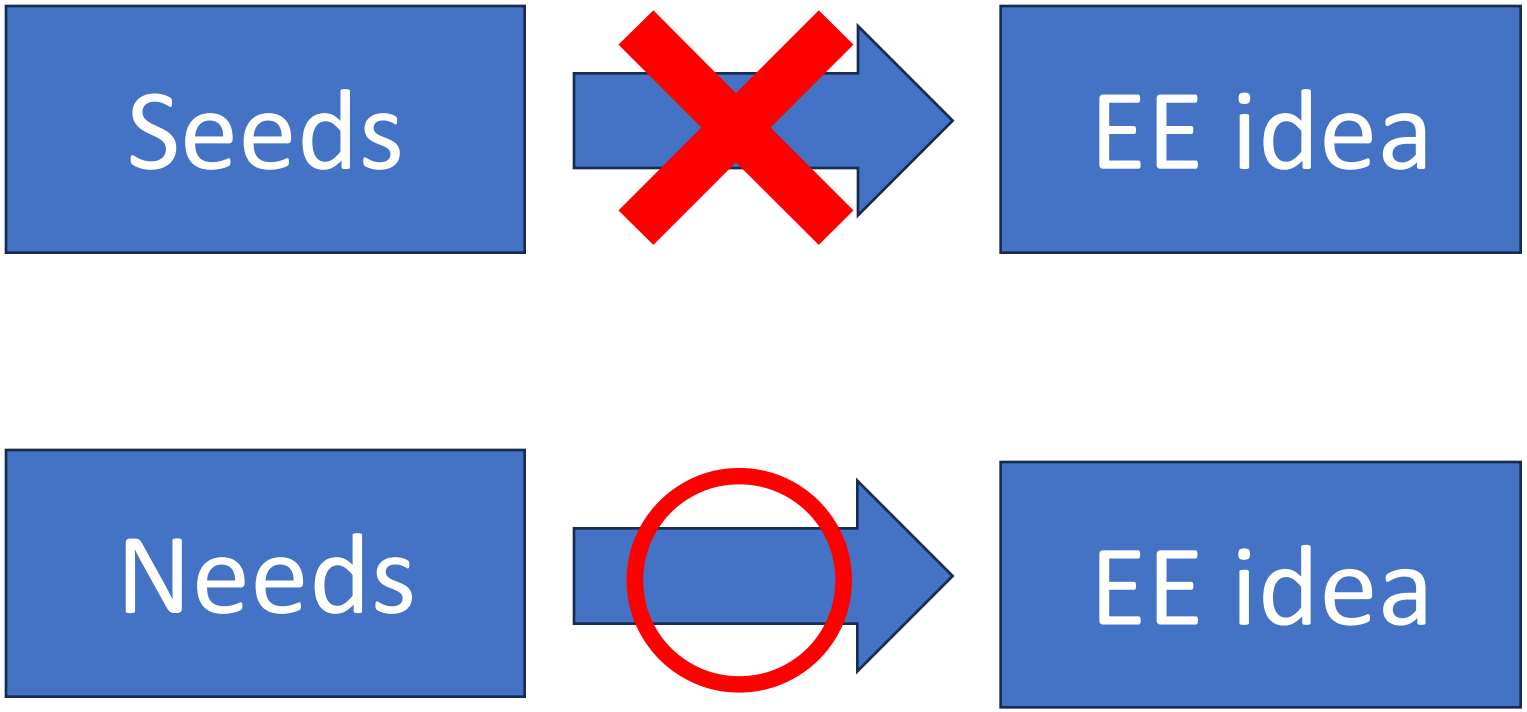


Multi-wire gripper



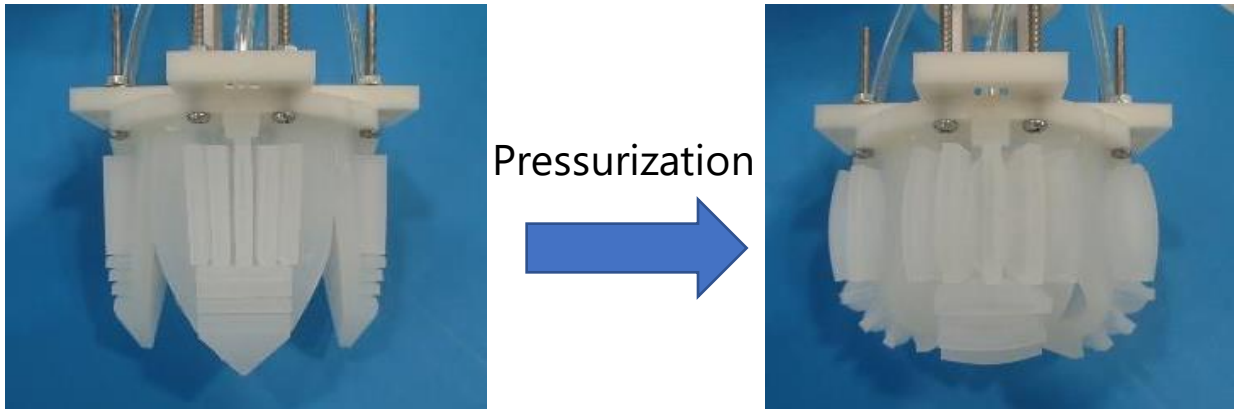
Shovel gripper

Our approach



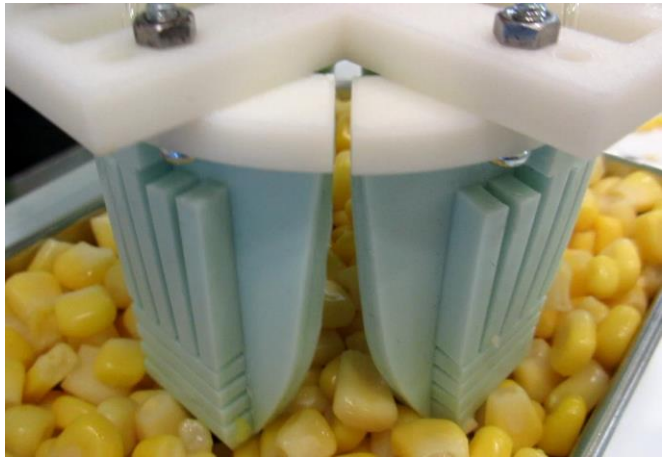
1. Wrapping gripper

Granular food

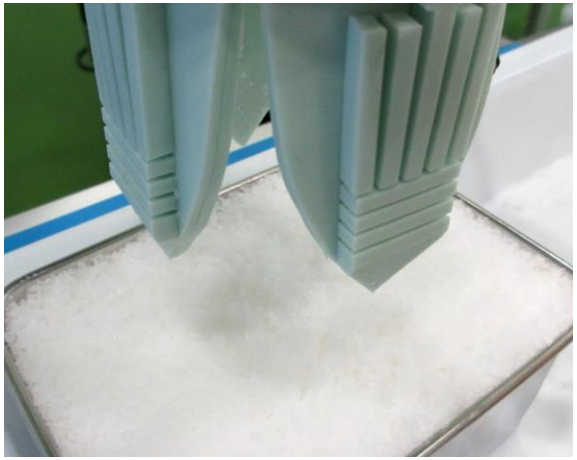


Wrapping gripper

Grasping of chopped green onion



Grasping of corn



Grasping of salt

Kuriyama et al., IEEE RoboSoft 2019

System Performance

Grasping results of specified weight

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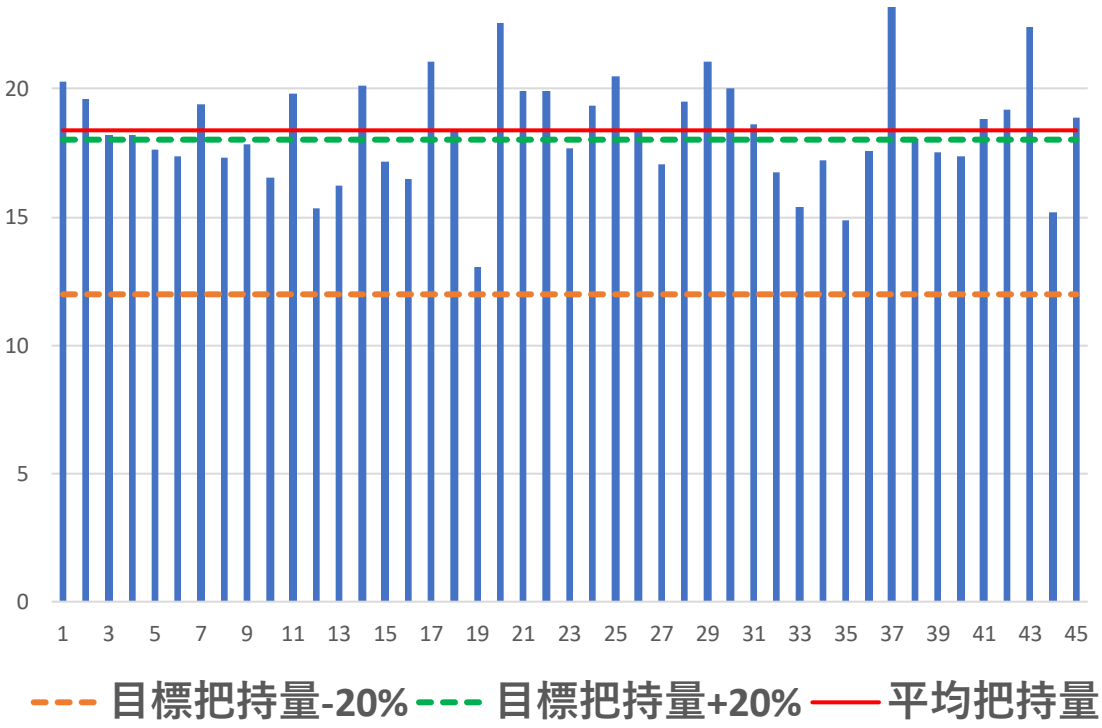
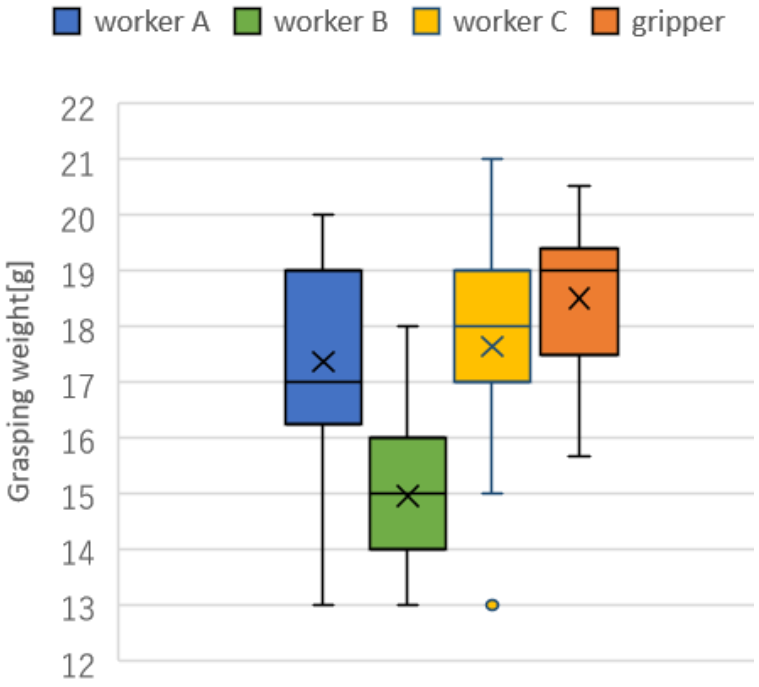
Grasping Chopped green onion



Average	STD [g]	RSTD
18.4 g	2.09 g	11.4%

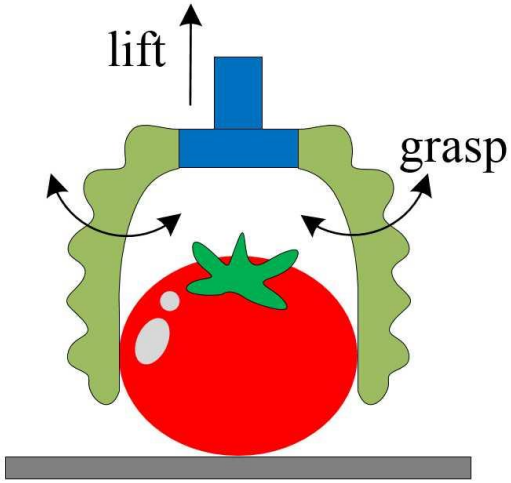


Results comparison with human worker

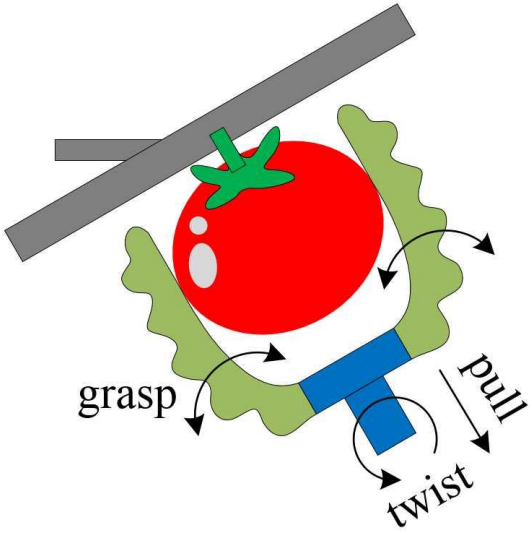
2. Circular shell gripper

Daifuku mochi

Harvesting tomato



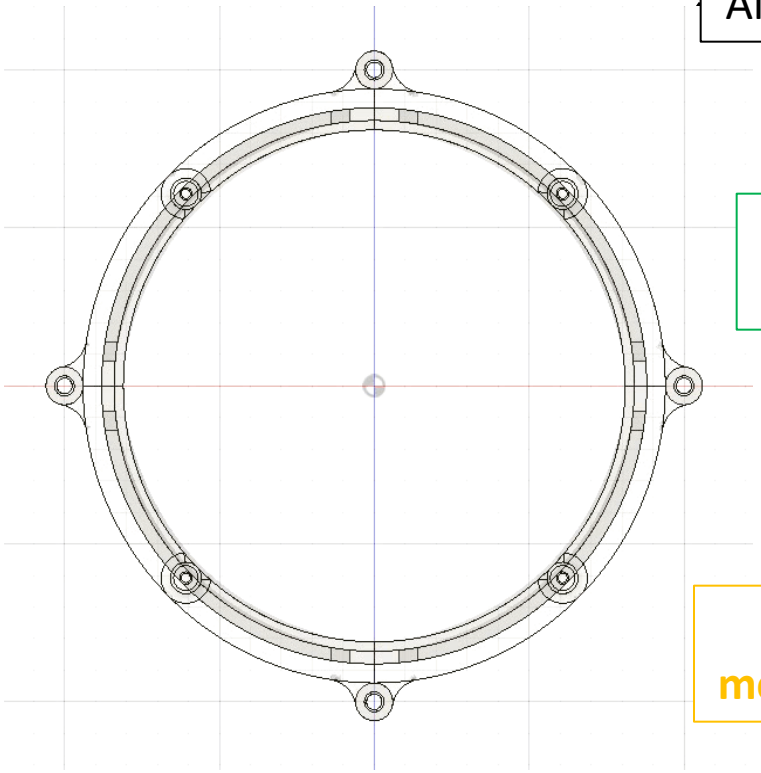
Grasping and lifting



Pulling while twisting

A gripper capable of doing both

Idea of shell gripper

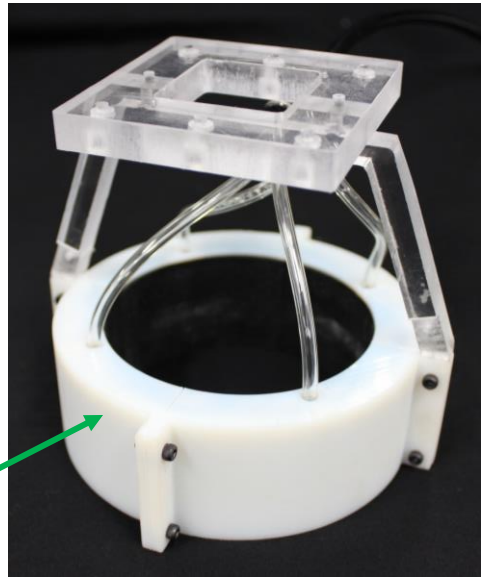


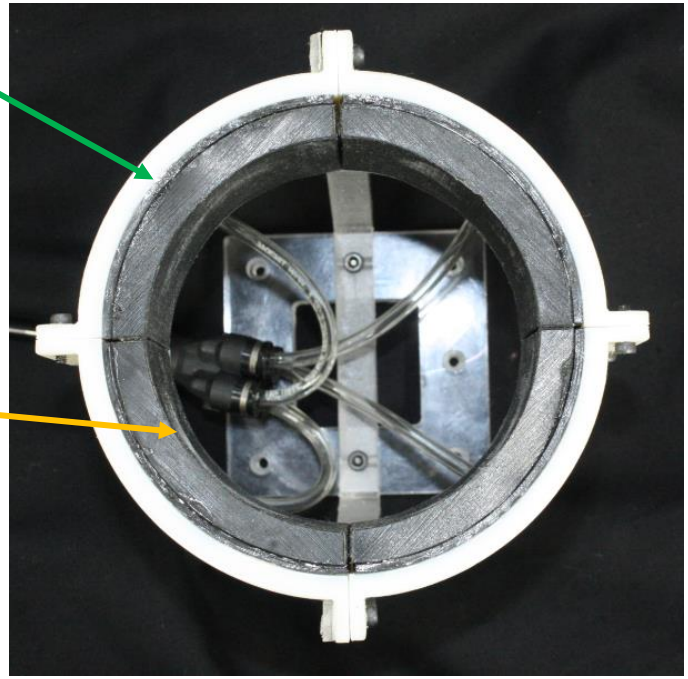
Shell gripper image

Air chamber

Rigid shell

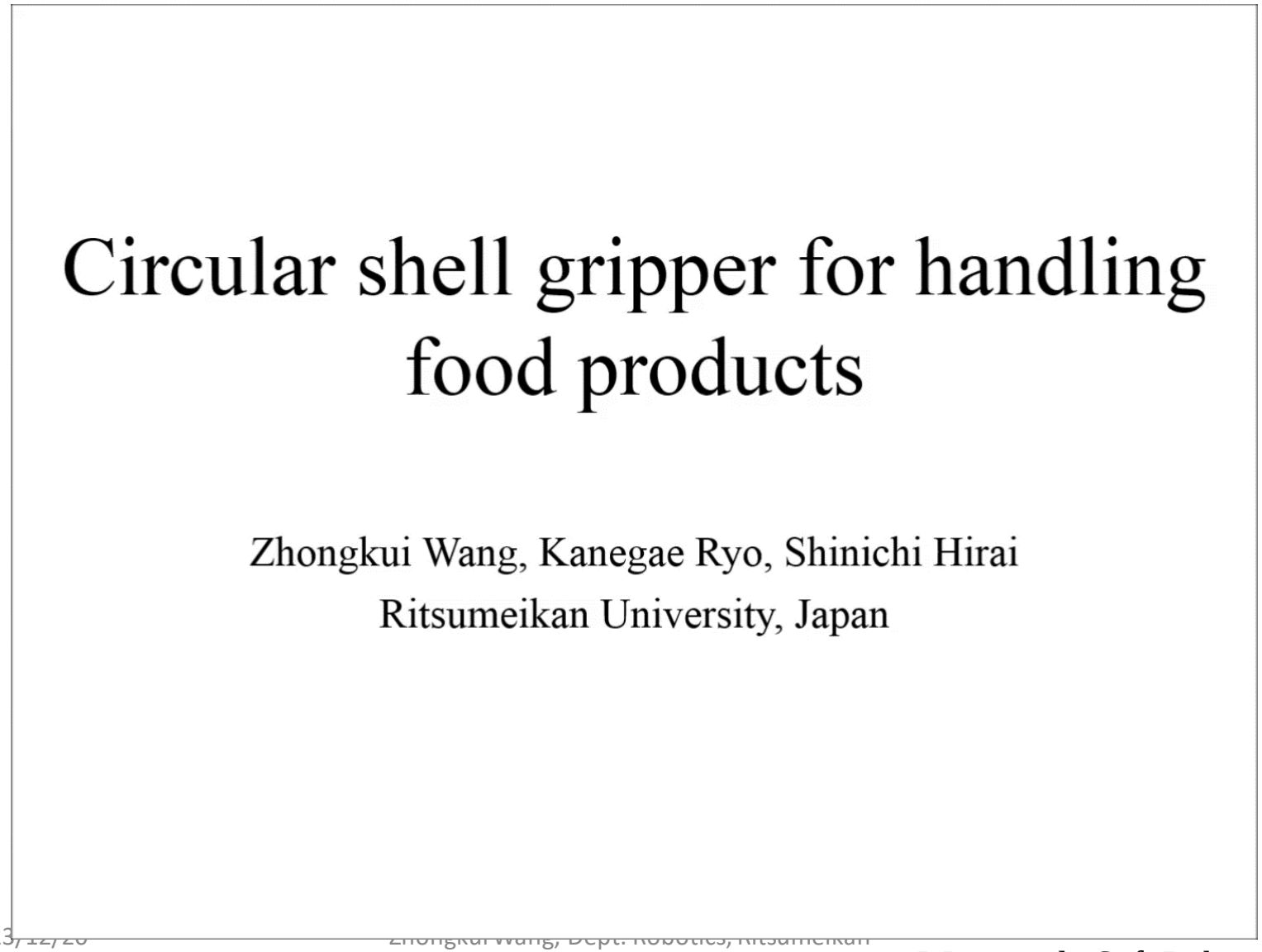
Soft membrane





Fabricated shell gripper

Grasping performances



Circular shell gripper for handling food products

Zhongkui Wang, Kanegae Ryo, Shinichi Hirai

Ritsumeikan University, Japan

Wang et al., Soft Robotics, 2021

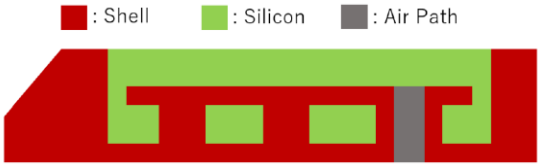
3. Parallel shell gripper

Cucumber packaging by human

System requirements：

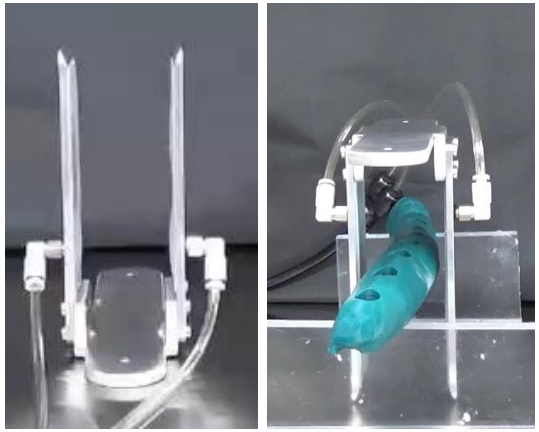
1. Productively: 30 t / day
2. Grasping
3. Takt time: 7 sec
4. No damage to product
5. Durable to thorns
6. Small gaps among products
7. Adaptable to differences
8. Grasping failure detection
9. Remote monitoring
10. Low cost

Parallel shell gripper



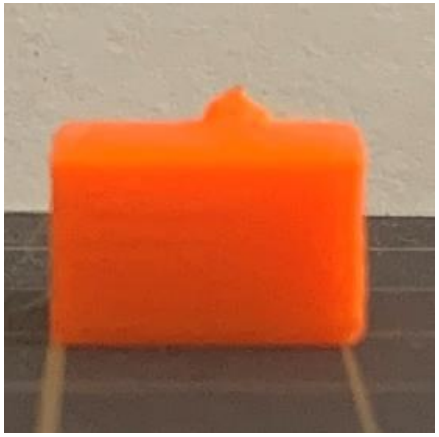
Cross-section view

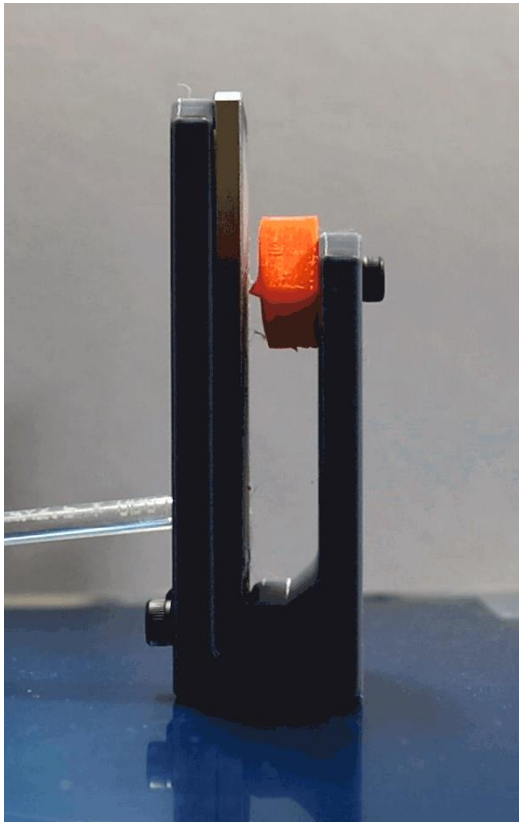
Prototype



Grasping test

Durability tests



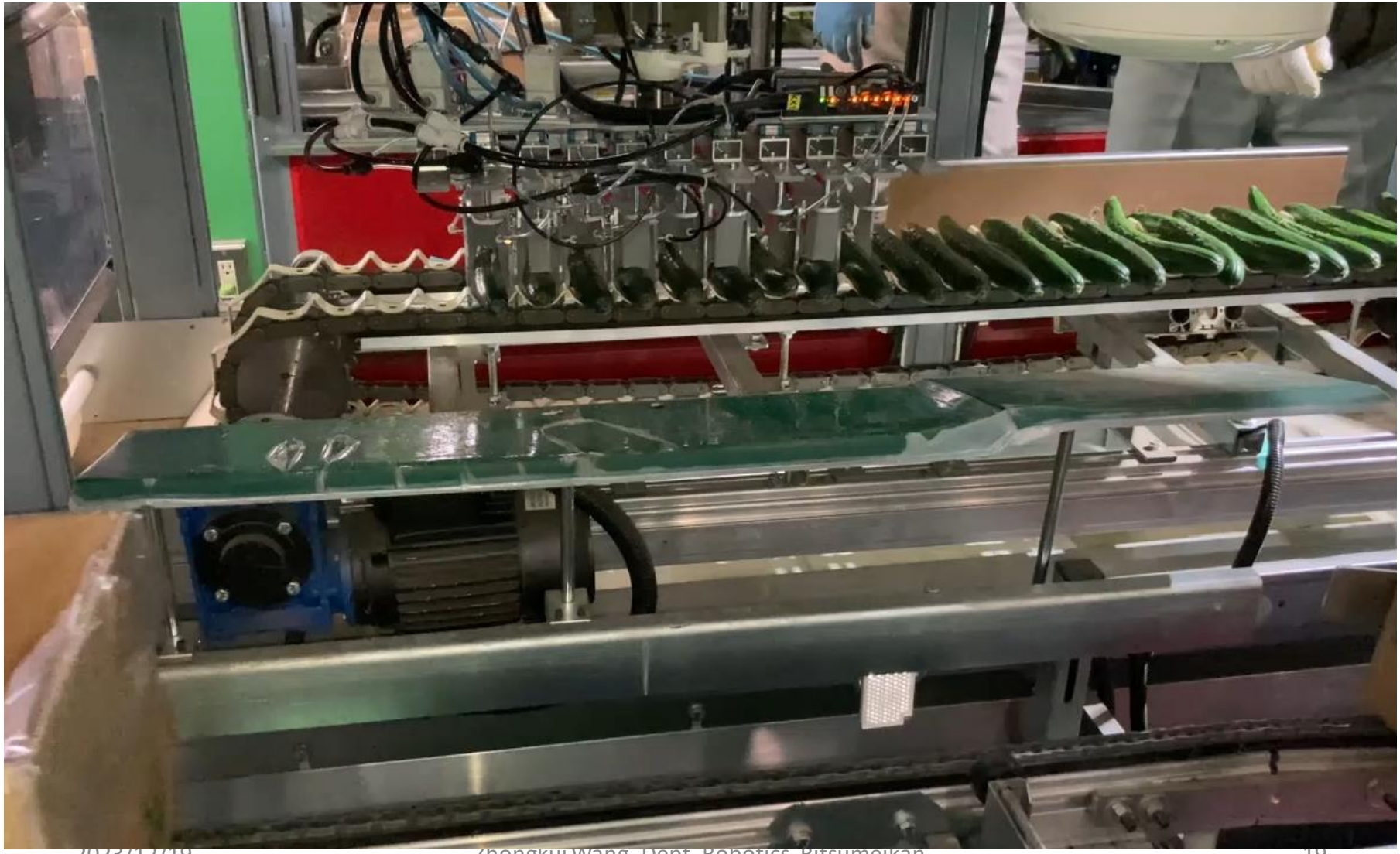


Sample of cucumber thorn

材質	SUS304		
印加圧力 [kPa]	18	16	14
ふくらみ量（算出値）[mm]	9.75	8.77	7.78
耐用回数	15015	16779	10 万回以上

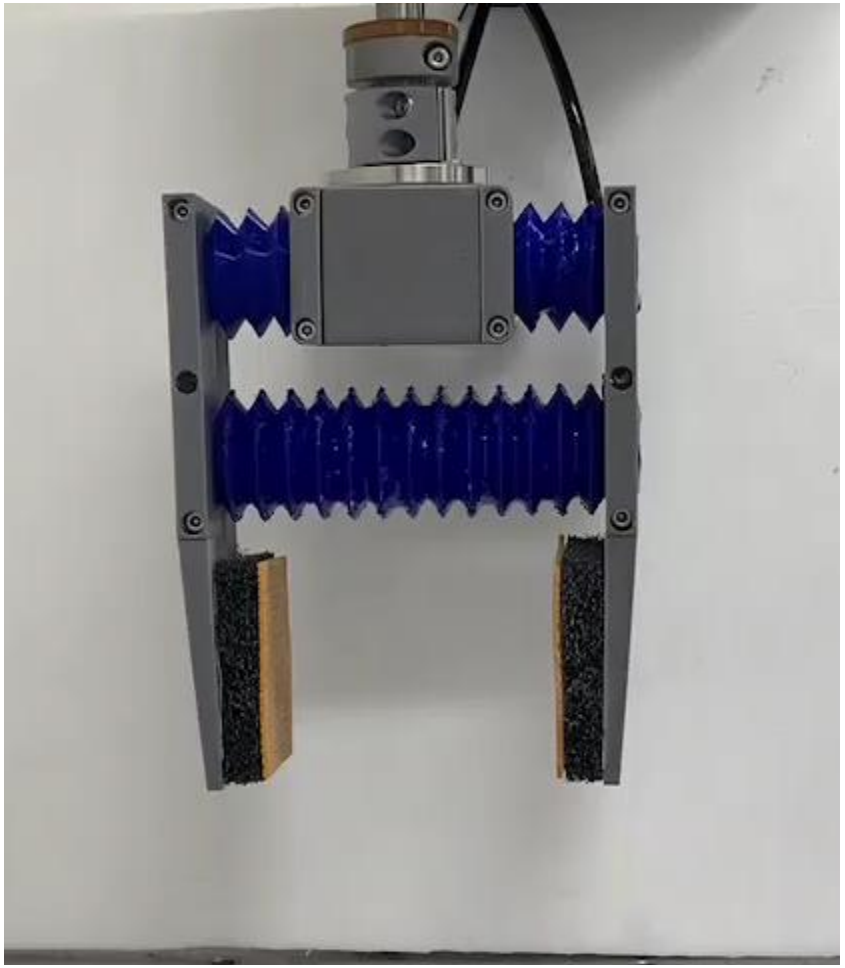
Kanegae et al., IEEE RCAR 2020

Field experiment



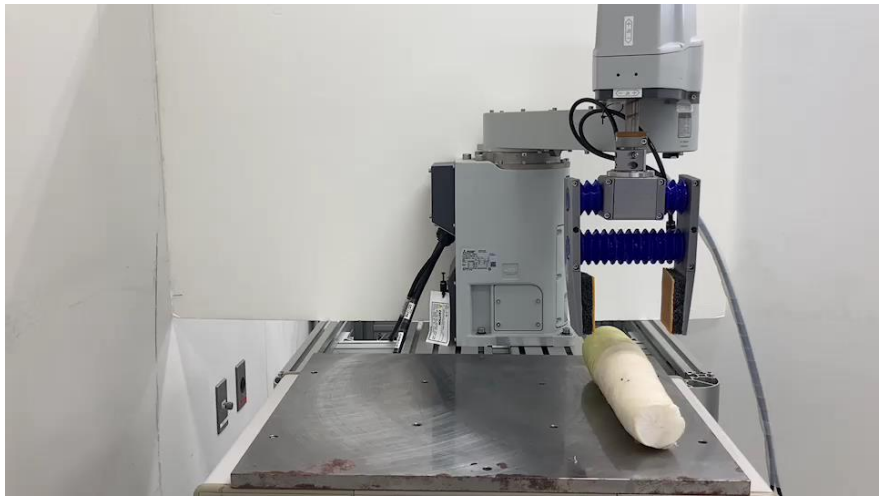
4. Soft bellows hand

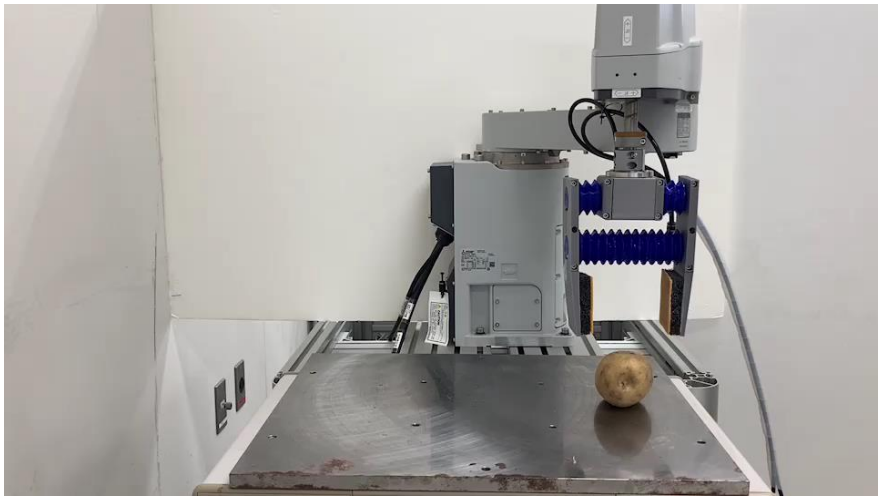
Arrangement of white radish

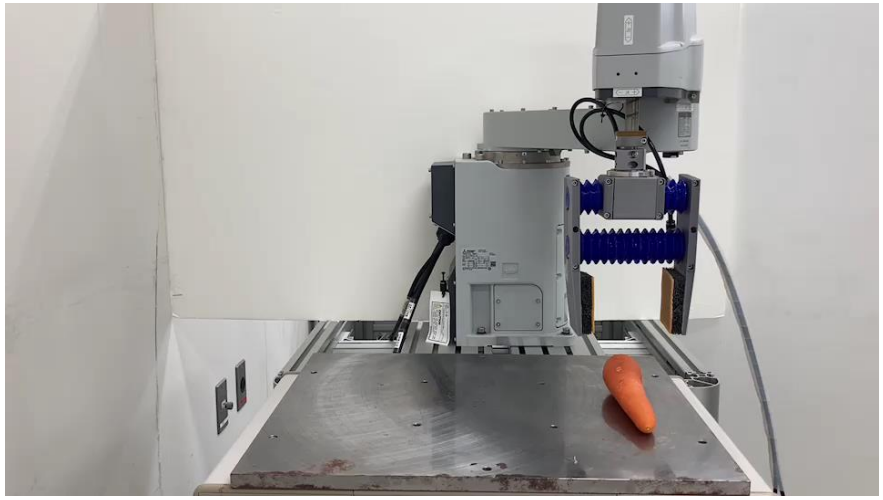


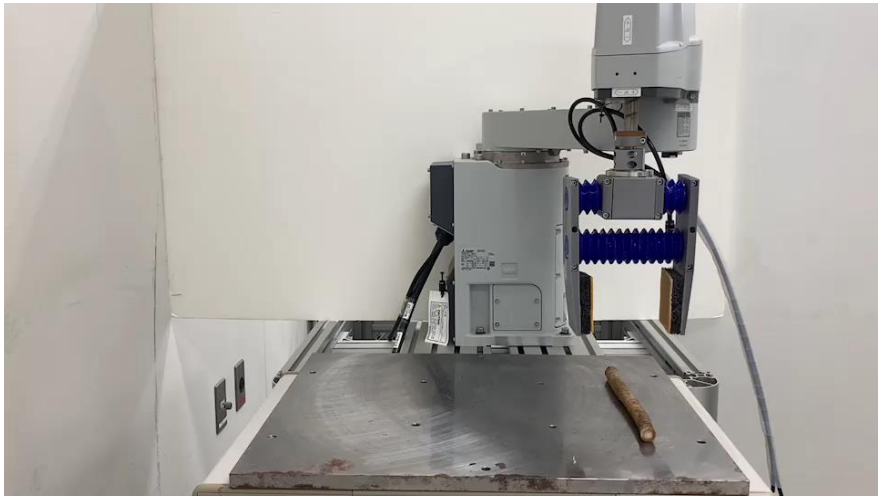
Soft bellows hand

Grasping of agricultural products

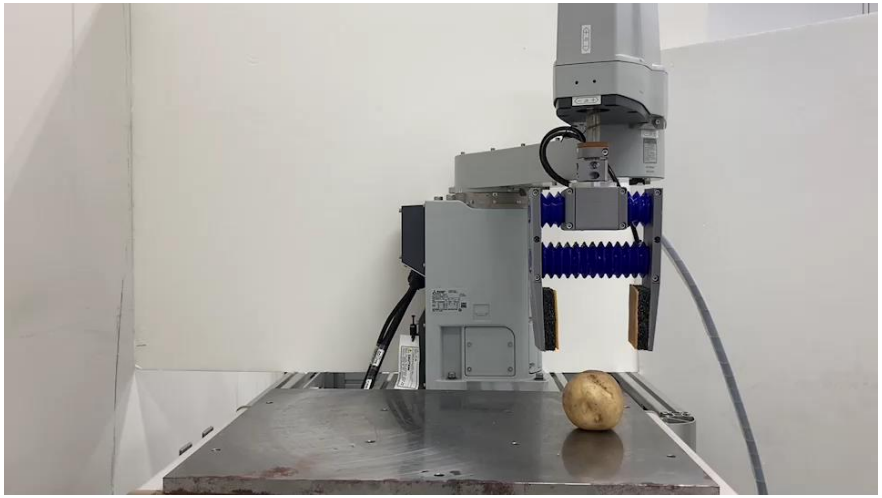


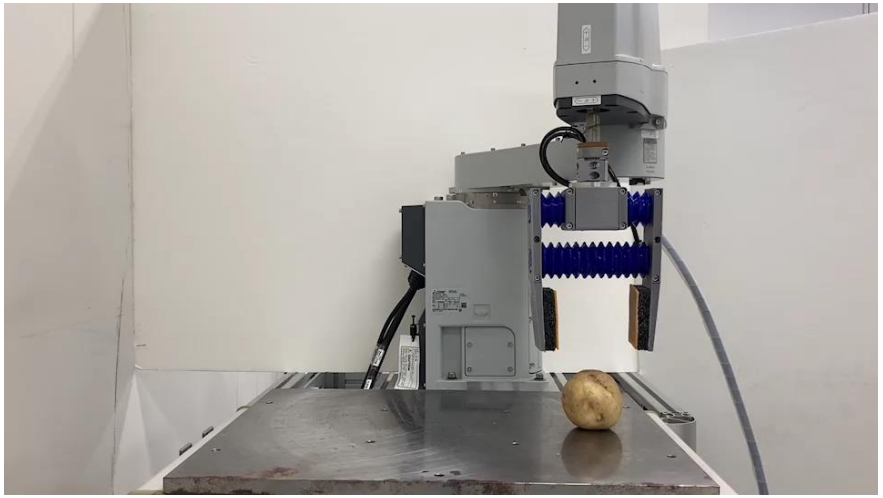


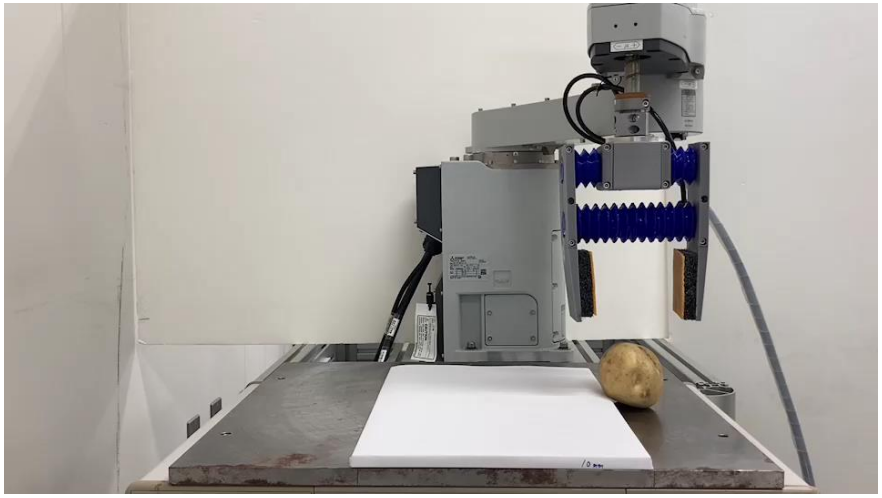


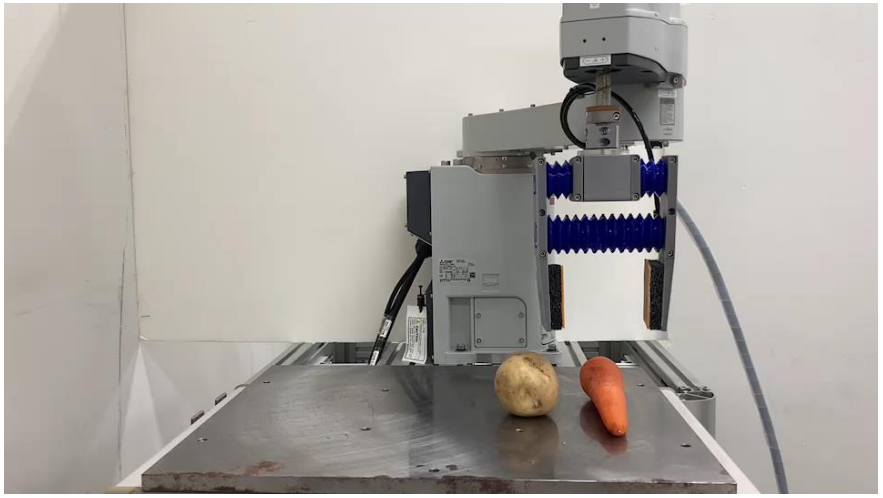


Grasping with contact





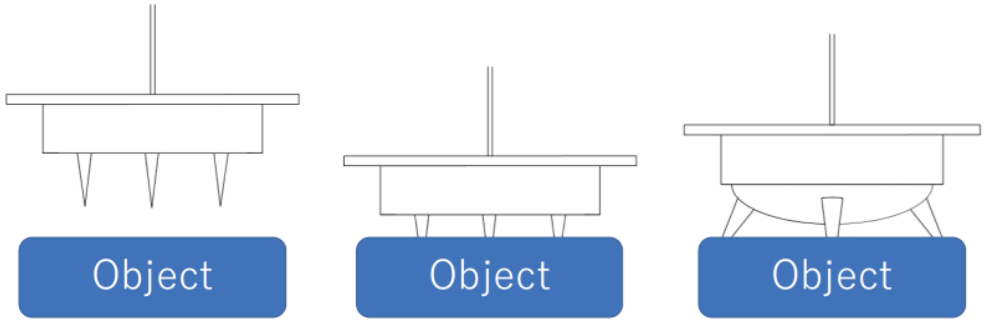




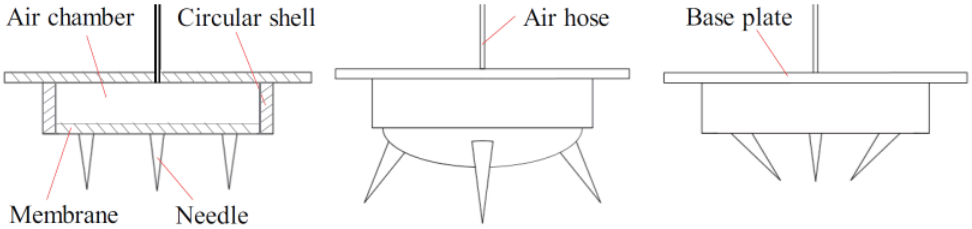
5. Needle gripper

Removing defective product from tray

Idea of needle gripper

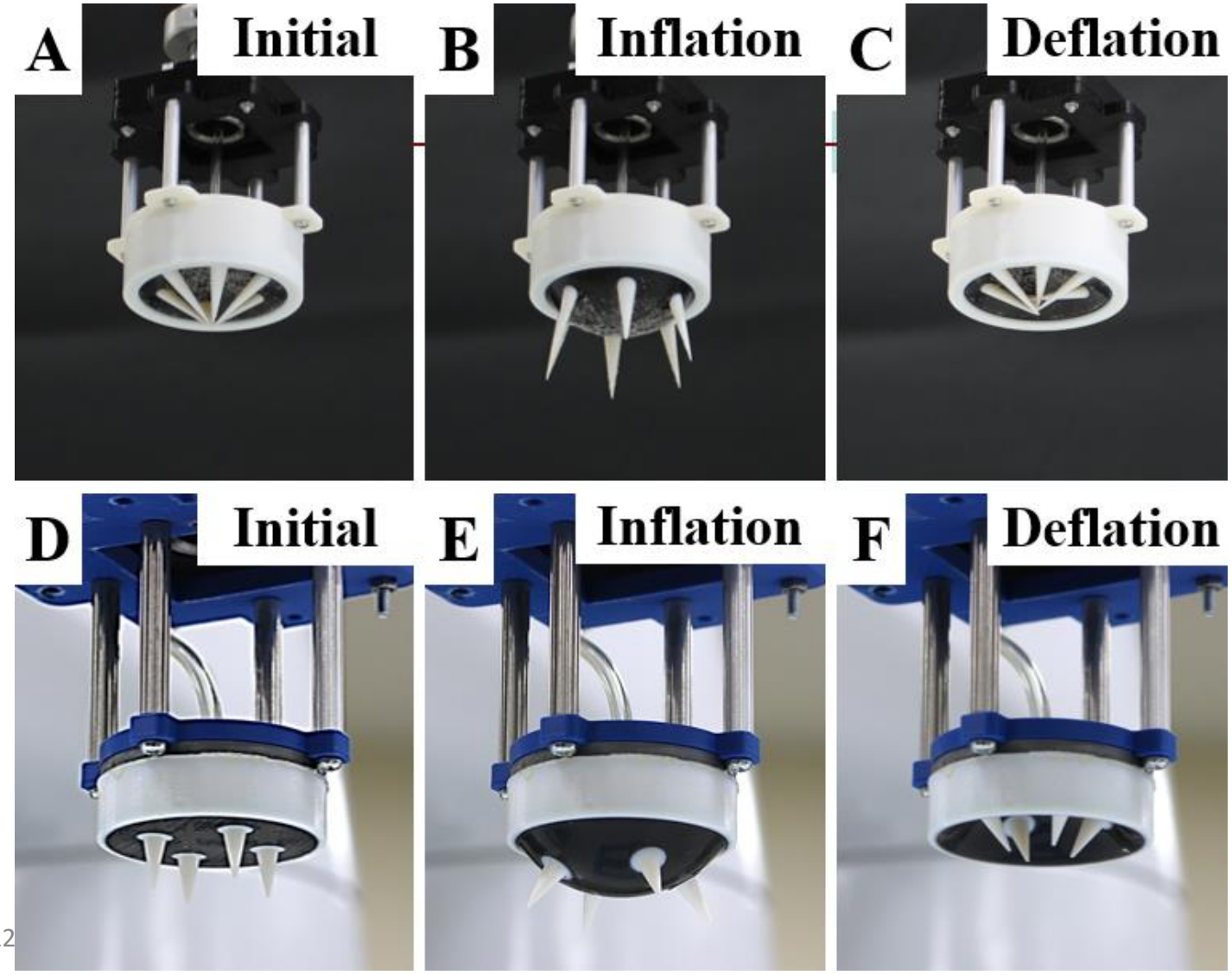


Grasping by piercing

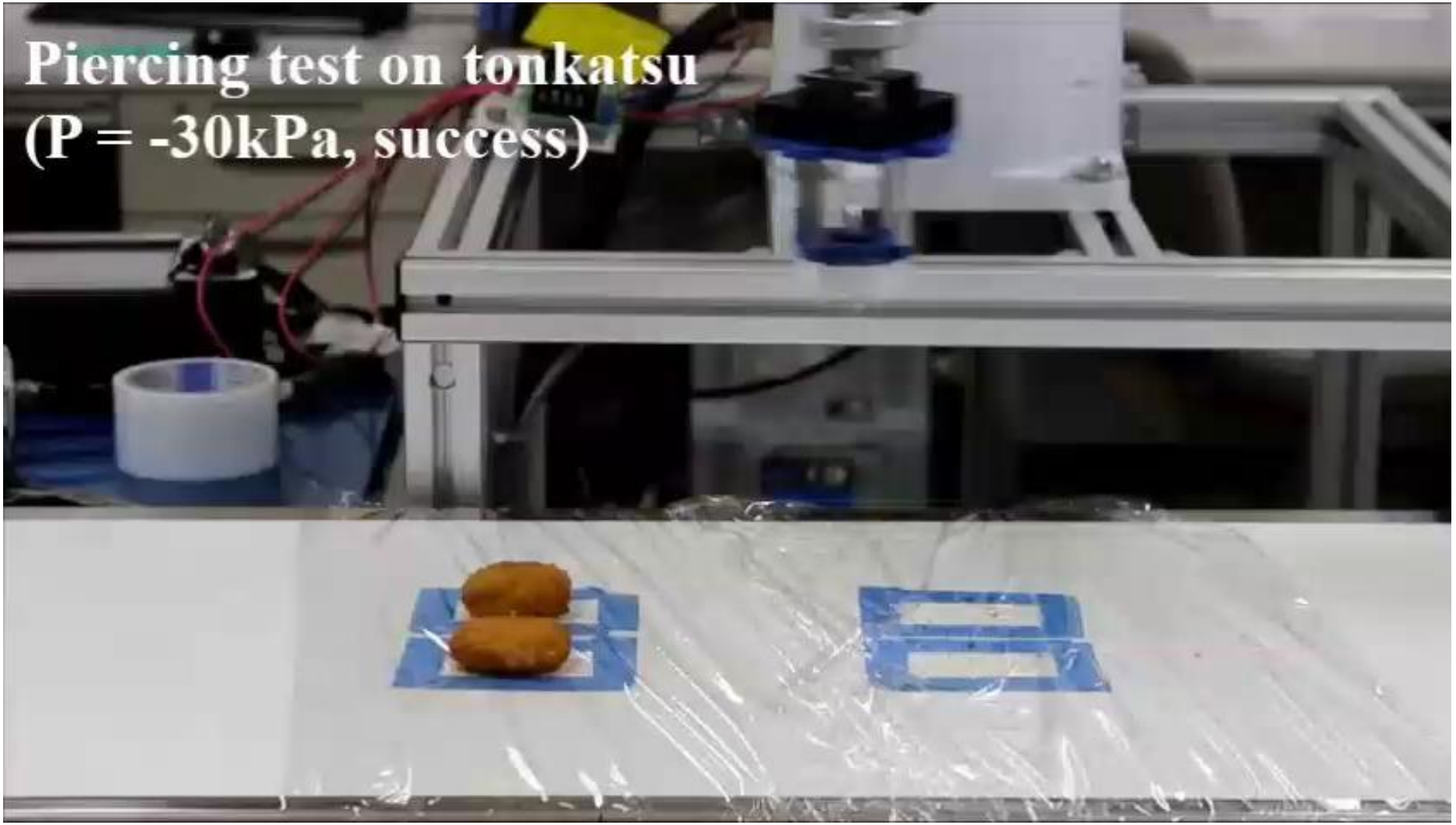


Grasping by pinching

Fabricated needle gripper



Grasping by piercing



Grasping by pinching

Makiyama et al., IEEE RCAR 2020

6. Multi-wire hand

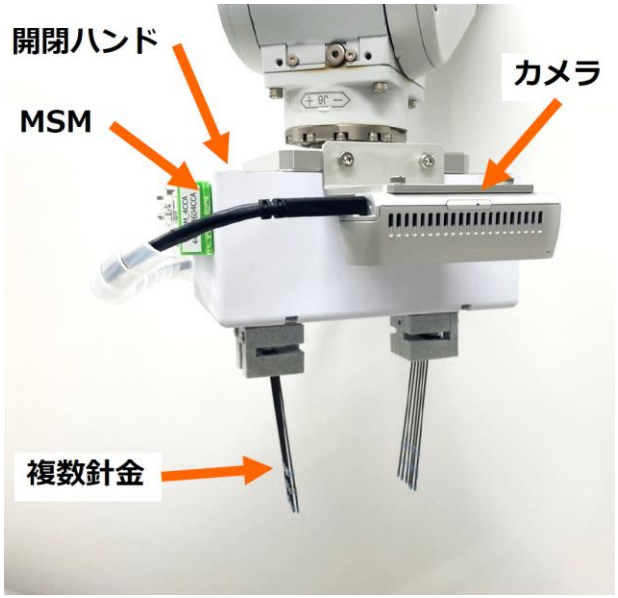
Arrangement by human

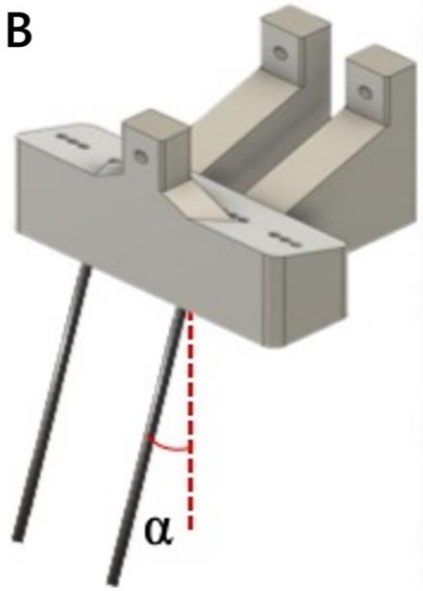
Arrangement target

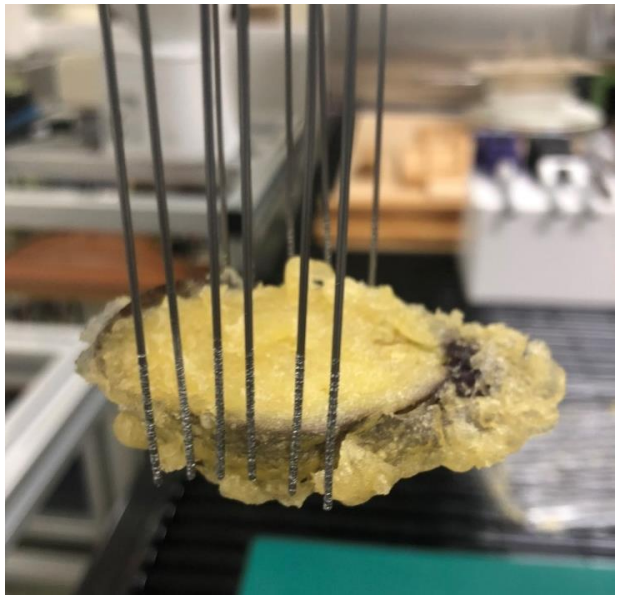
Task definition

- 5 categories tempura
- Minimum grasping force
- Shrimp tail upward
- No overlap among objects
- 3D arrangement
- High speed

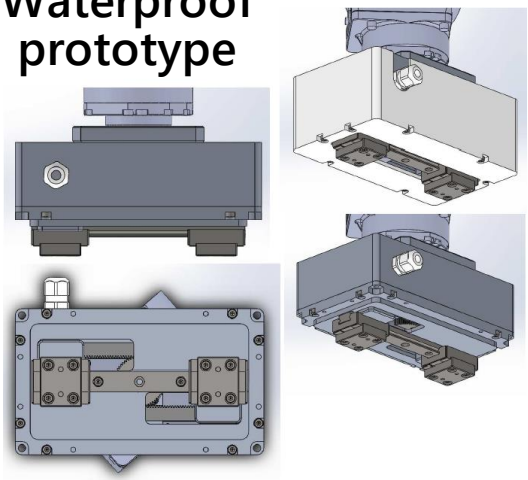
Idea of multi-wire hand

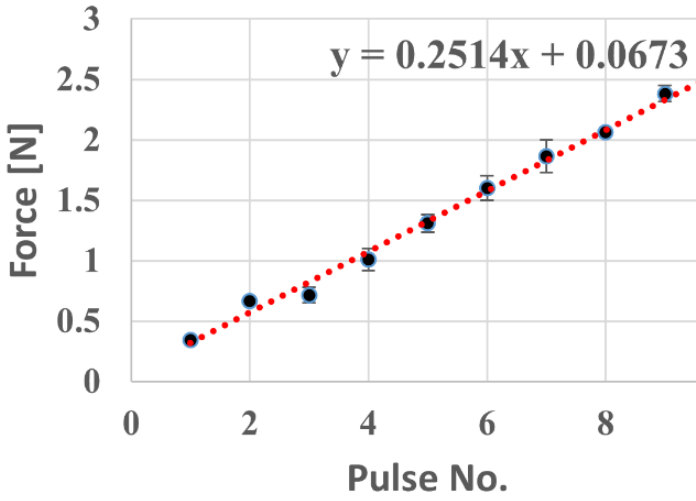






Waterproof prototype





Minimum force without sensor
≒0.35 N

Automatic food arrangement

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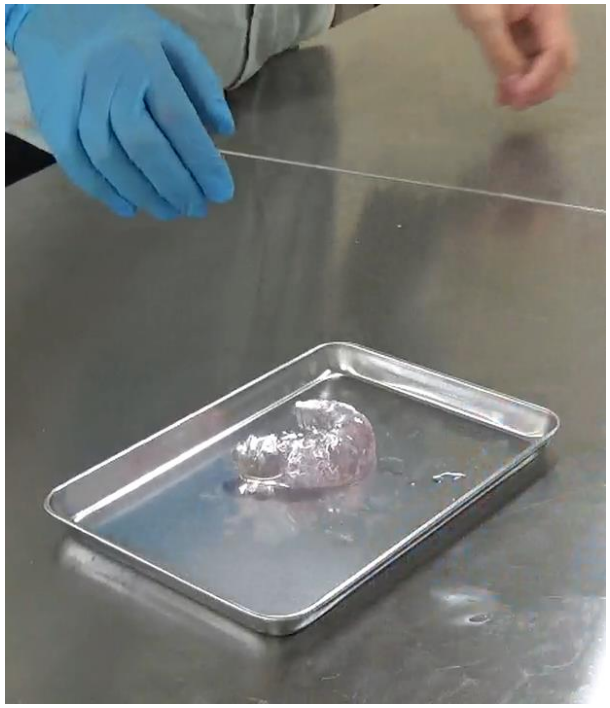
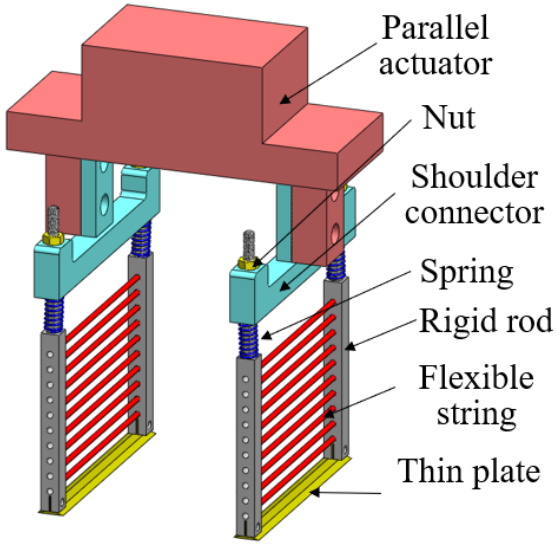
7. Scooping-binding hand



ゲルサンプル(タコの足)の把持
(Gel sample: octopus leg)



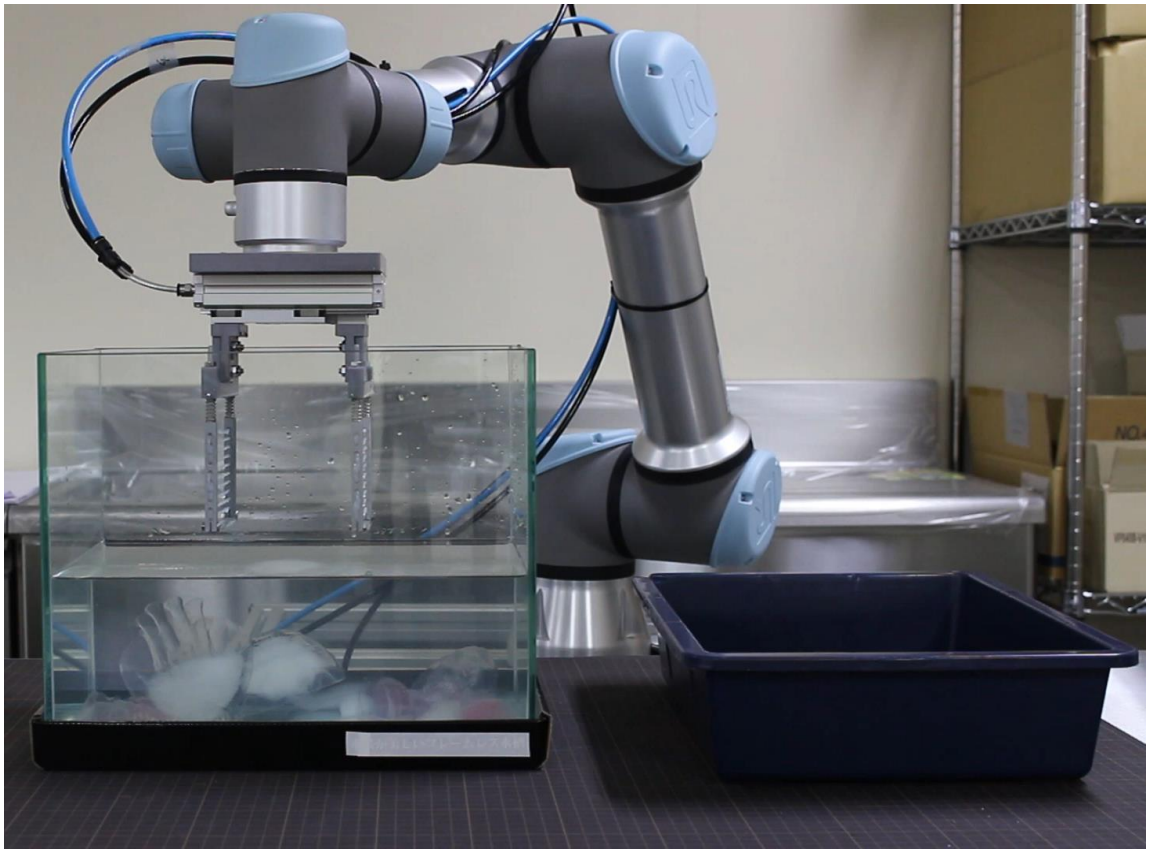
Gripper design

掬い込みハンド
Scooping-Binding hand

掬い込みハンドでの把持
Grasping using the scooping-binding hand

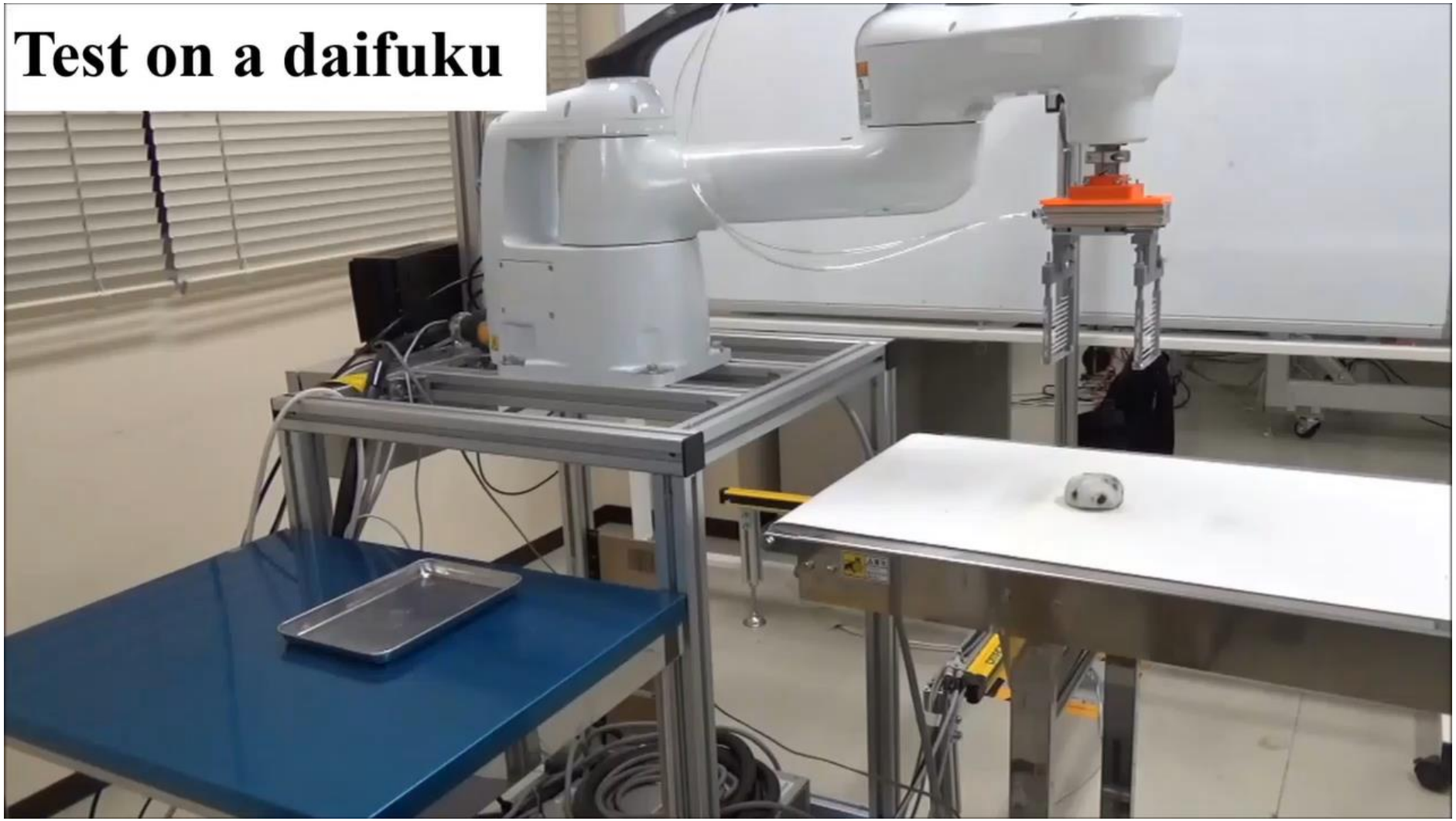
Grasping gel jellyfish

ゲルクラゲサンプル
Gel sample of a jellyfish



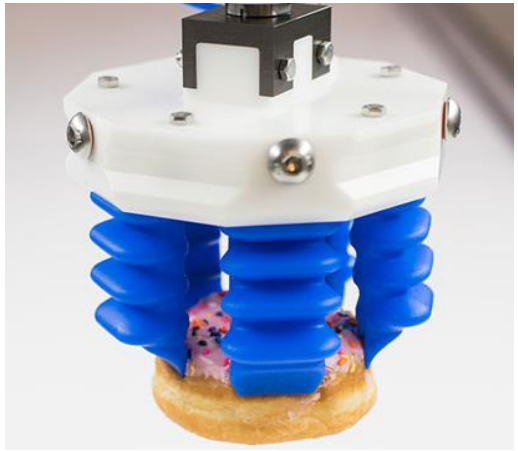
水中でのゲルクラゲ把持
Grasping the gel jellyfish from a water tank

Grasping various food products



Wang et al., Front. Robot. AI, 2021

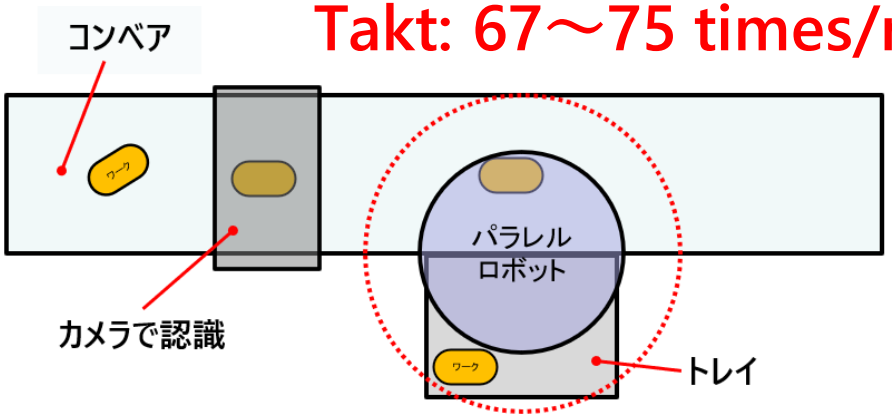
8. High-speed food handling

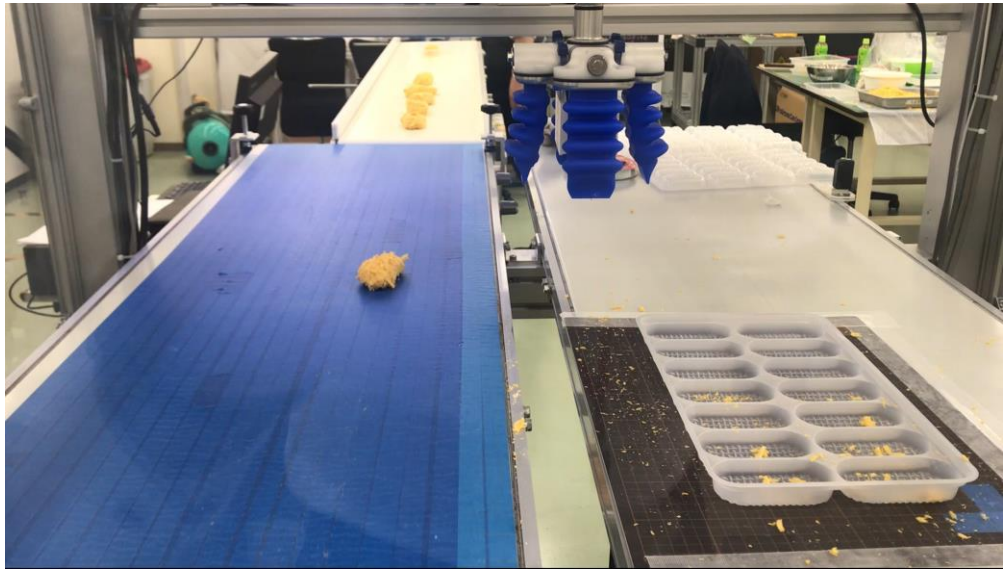


Commercial gripper

Bread-crumbs coated oyster

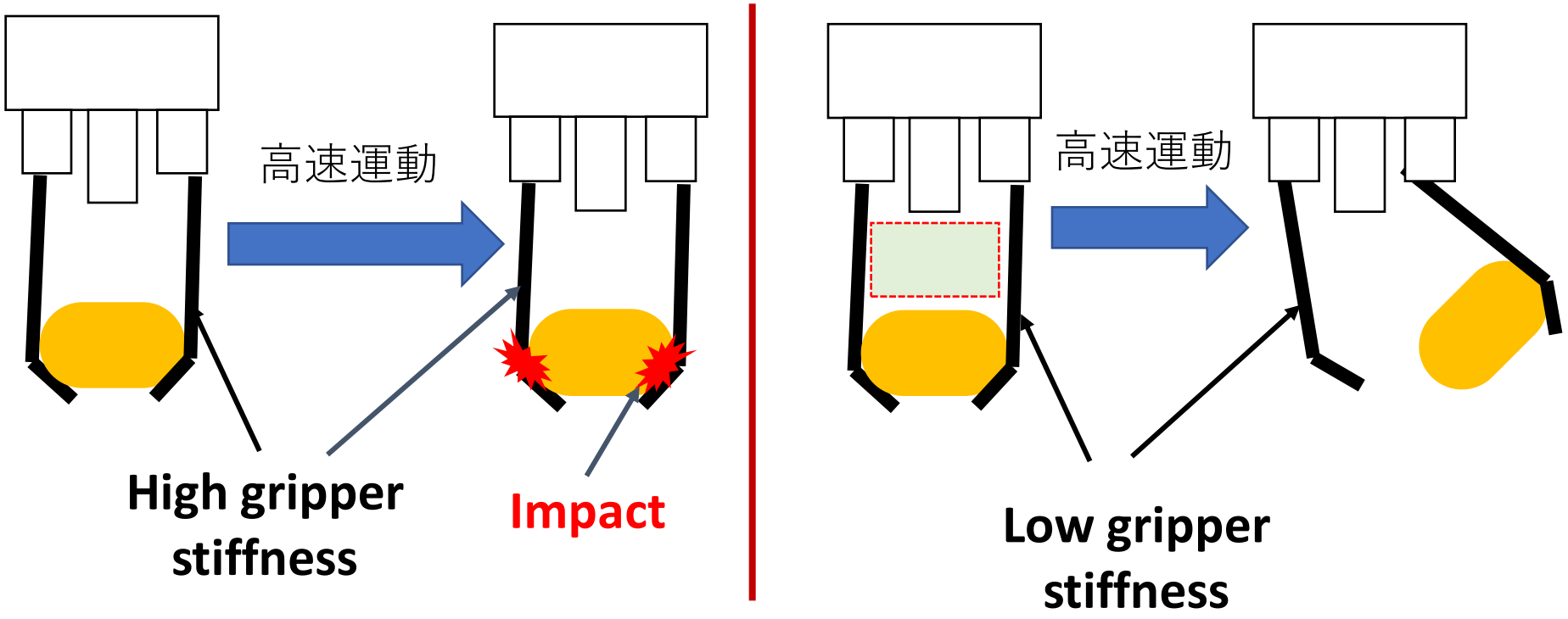
Takt: 67～75 times/min





Failed to handle at 70 times/min

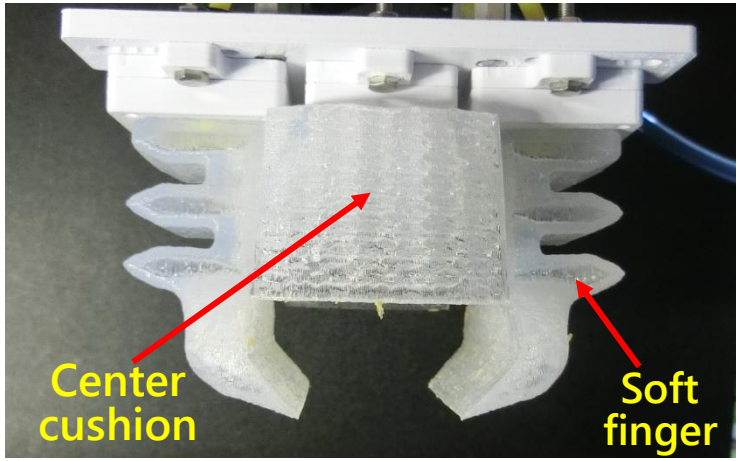
Reason of grasping failure



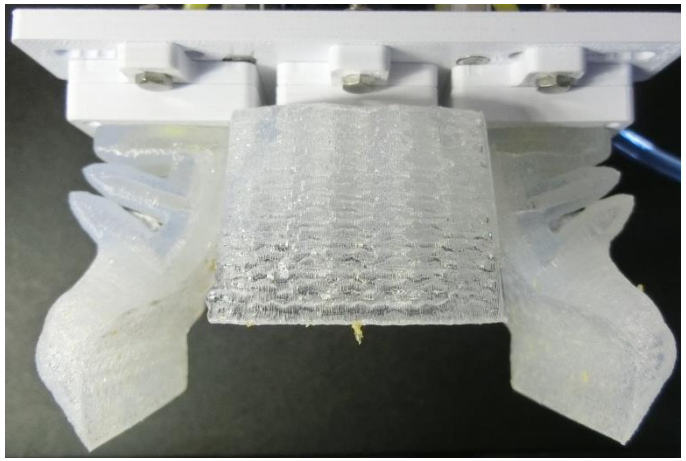
- **Appropriate gripper stiffness is required**
- **Constraining the movement of the target**

Shovel gripper

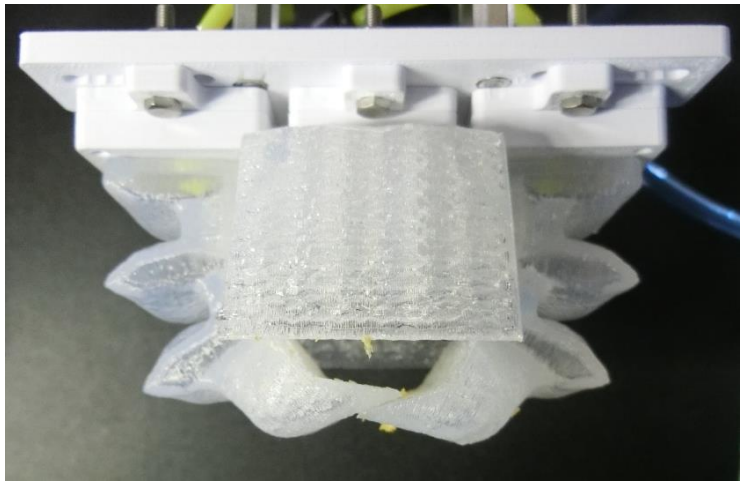
Initial state

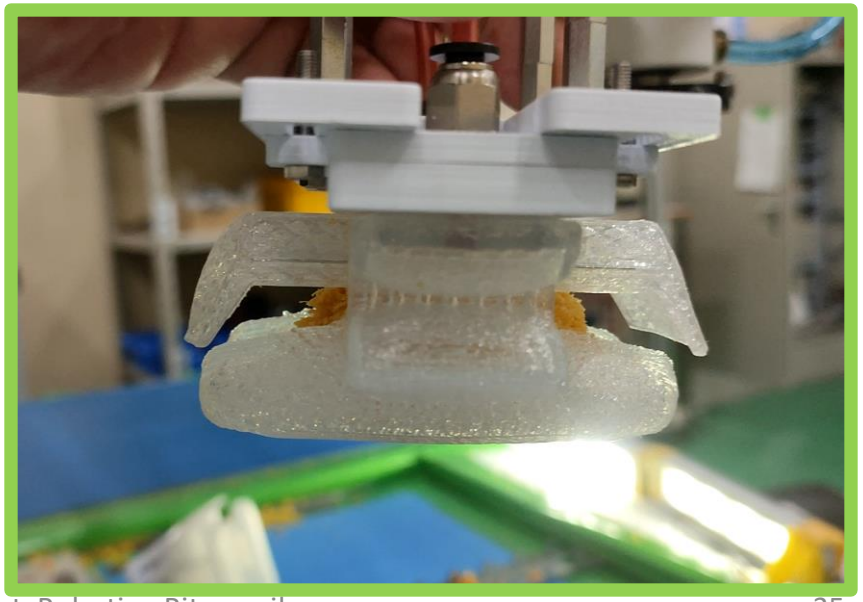


Open state



Close state





Design of gripper stiffness

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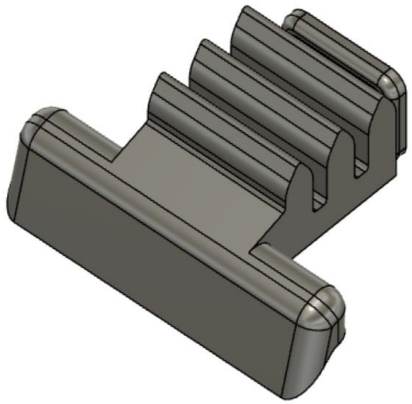
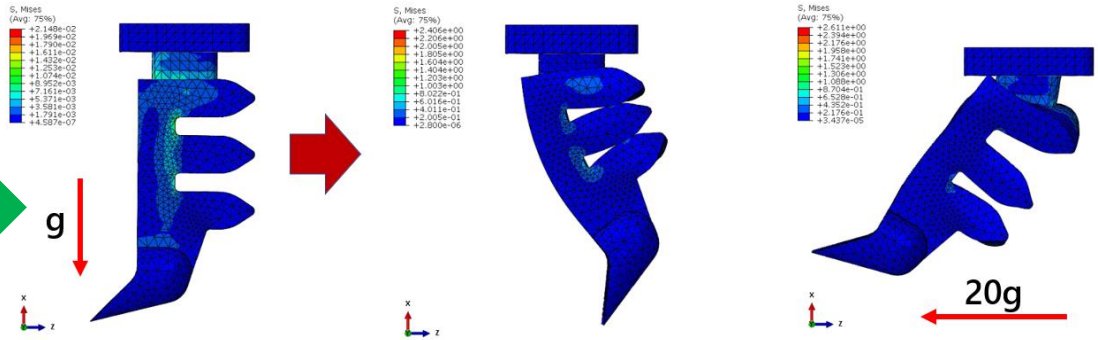
Target： **Contact area** ↑ **Stiffness** ↑

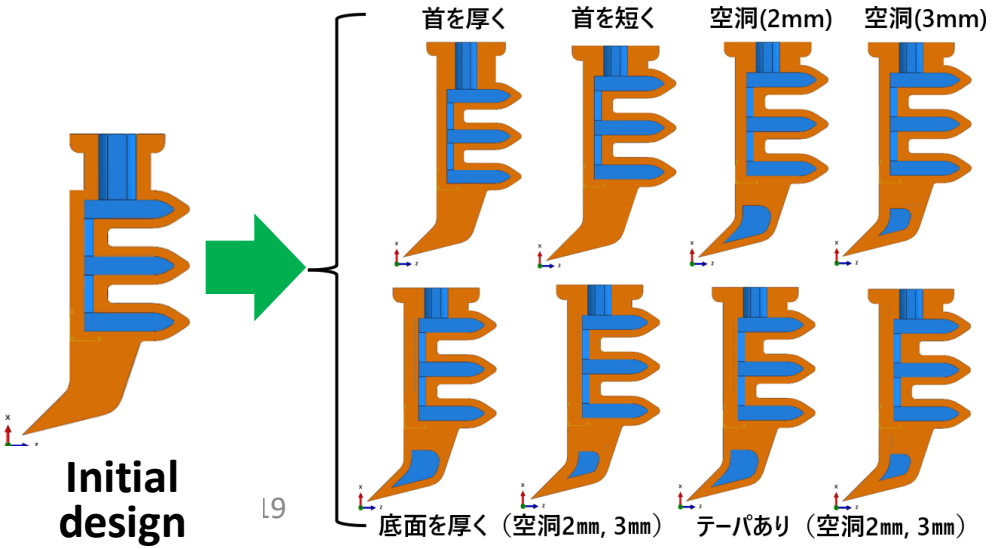


FE analysis



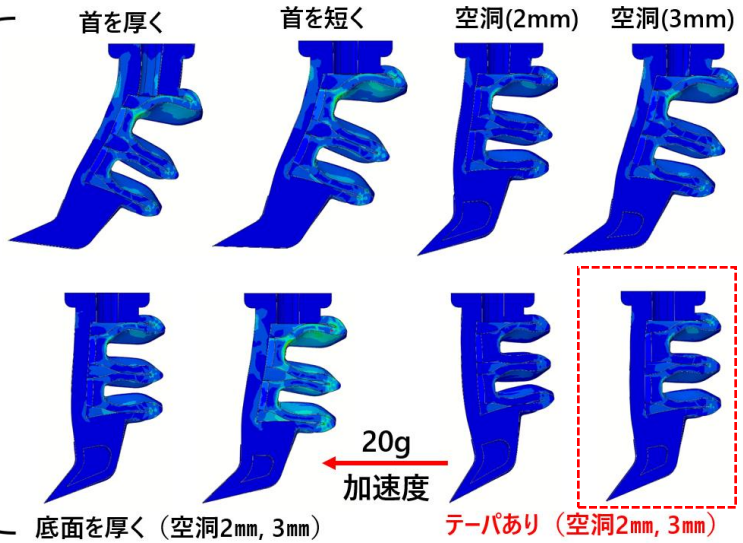
Gravity **Vacuum** **Acceleration**

Design variation

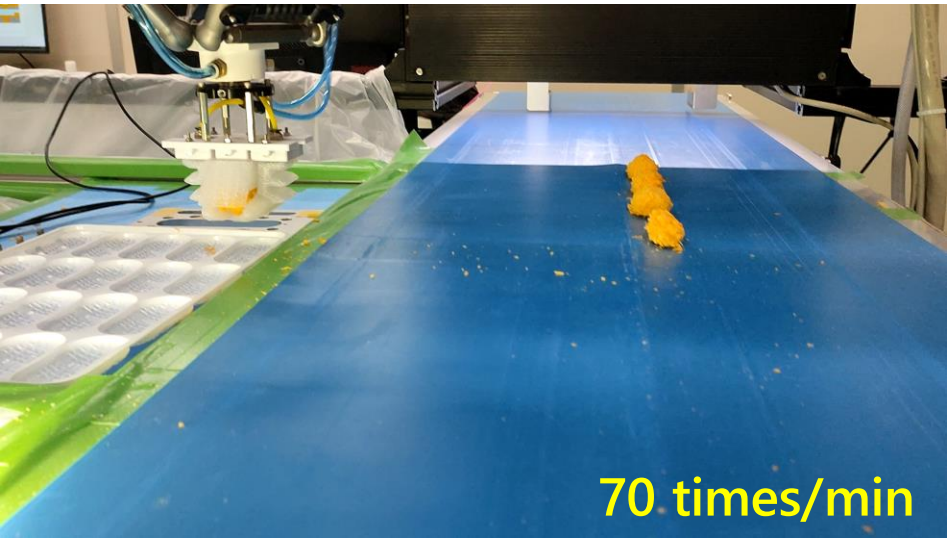


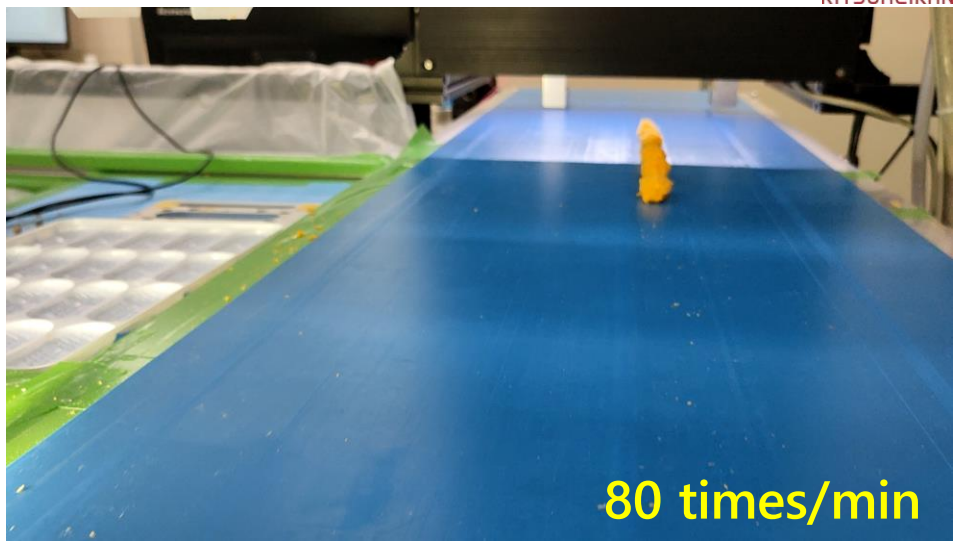
Initial design

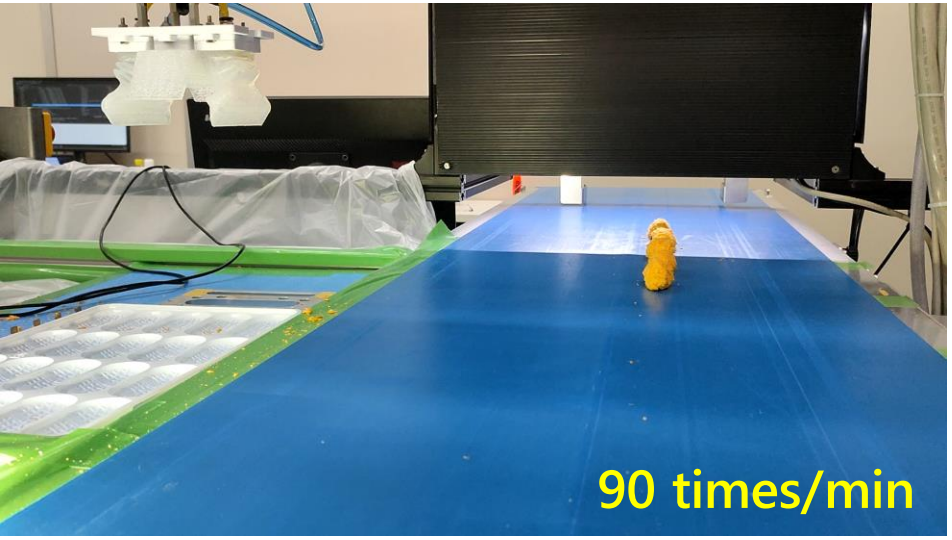
Sway due to acceleration

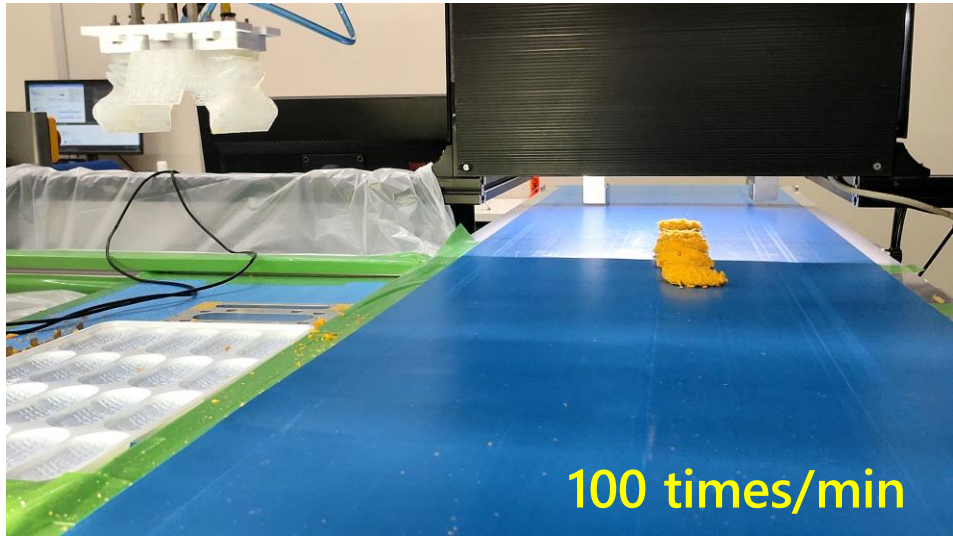


Handling tests (16 g target)

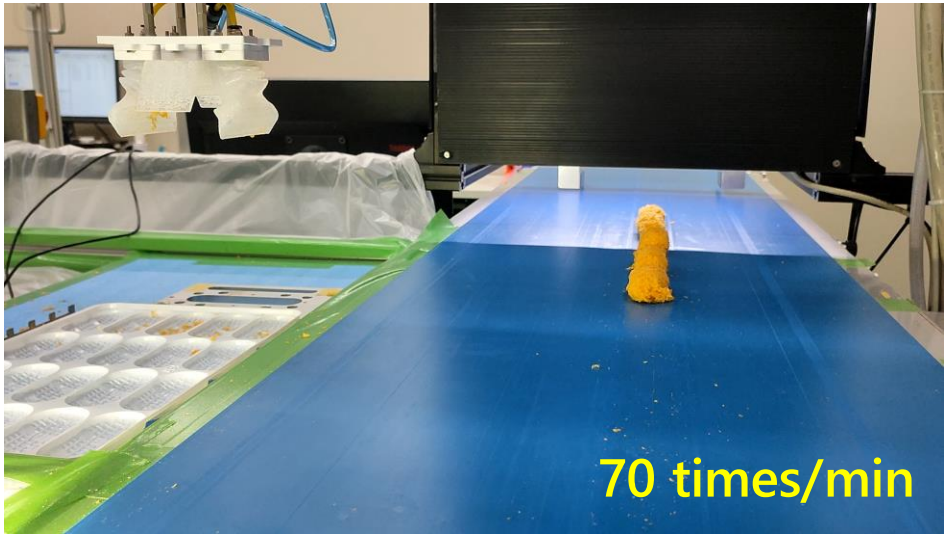


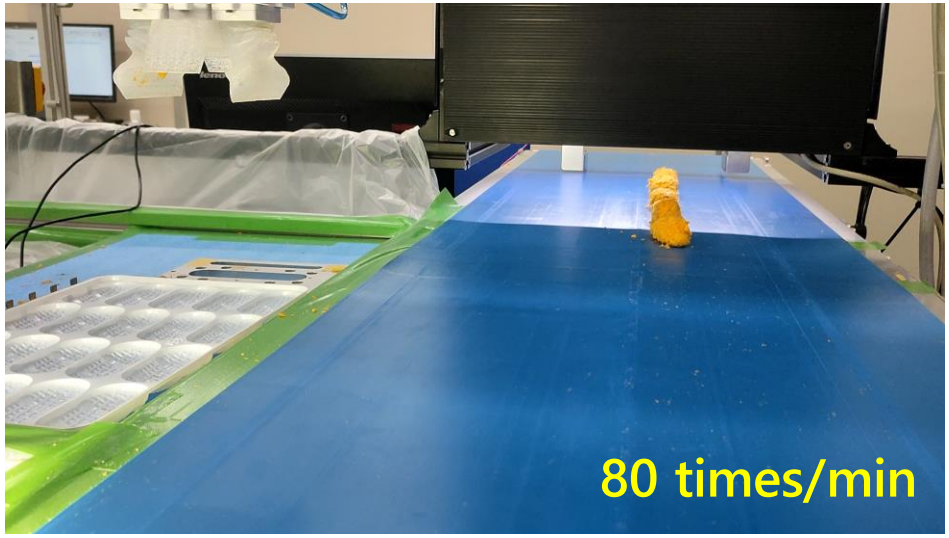


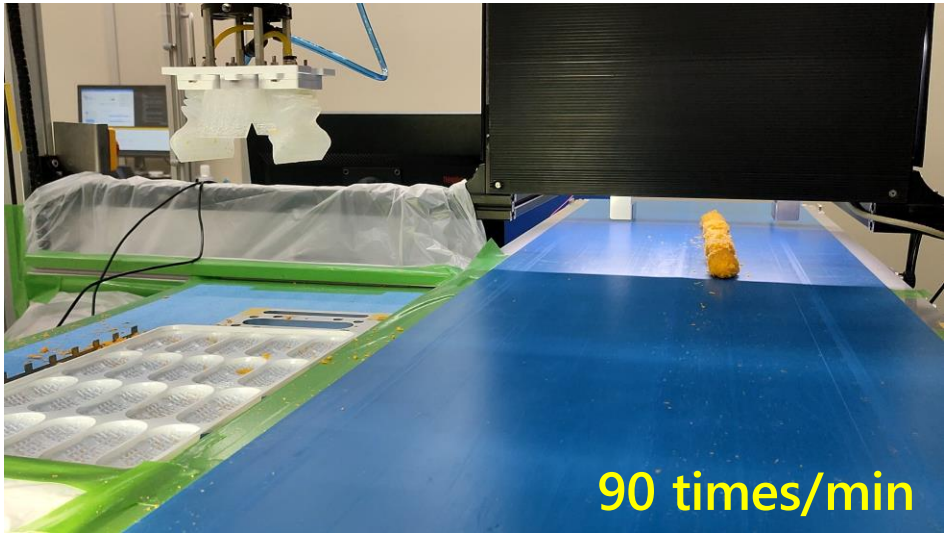


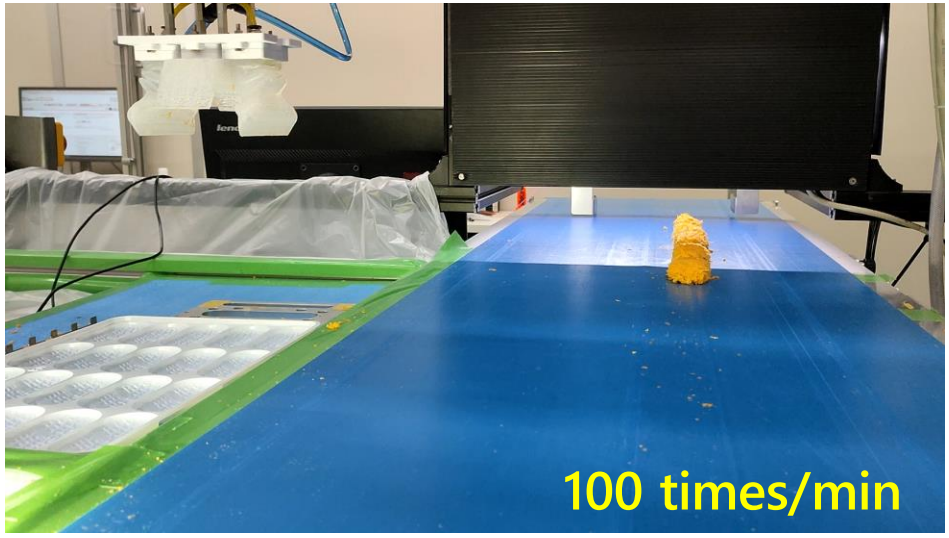


Handling tests (40 g target)





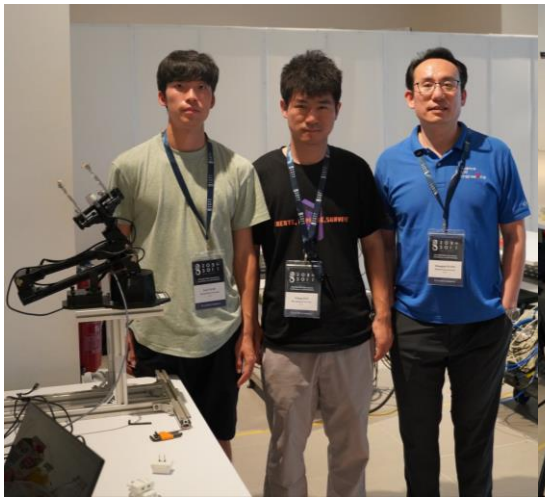




Food handling competition

Teams

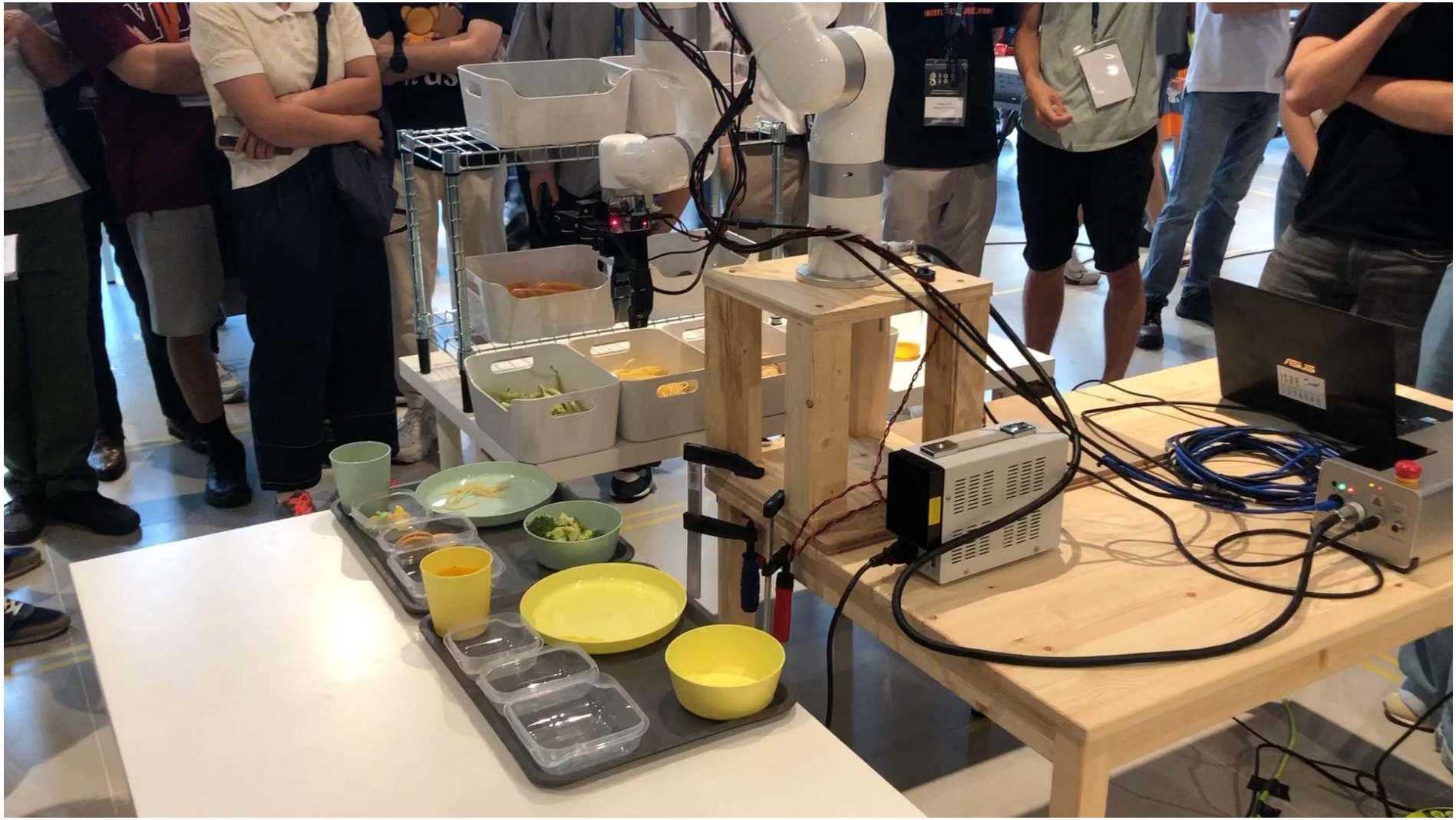
No.	チーム名	大学
①	ADMP Gripper	National University of Singapore (NUS)
②	SNAP ROBOTICS	Singapore University of Technology and Design (SUTD)
③	FANTASTIC	University of Bristol (UoB)
④	SIRSLAB	Italia Institute of Technology (IIT)
⑤	FLIPPER	École Polytechnique Fédérale de Lausanne (EPFL)
⑥	TEAM RITSUMEIKAN	Ritsumeikan University



IIT team

NUS team

EPFL Team



Ritsumeikan Team

Competition results

順位	点数	大学
1	170	Singapore University of Technology and Design (SUTD)
2	108	Ritsmeikan University
3	91	École Polytechnique Fédérale de Lausanne (EPFL)
4	30	National University of Singapore (NUS)
5	29	University of Bristol (UoB)
6	23	Italia Institute of Technology (IIT)

Future possible directions

- New EE ideas for handling various food and agricultural products at high-speed, especially fragile and heavy products;
- New EE ideas for handling living creatures;
- Easy and effective models for helping the control and design of soft EE;
- New fabrication methods that is easy accessible, efficient, and suitable for EE commercialization;
- New and smart materials that can change its properties according to the task, e.g., 4D material.

Report

- Think of one target object that is difficult to handle by conventional EEs;
- Write down the reason why it is difficult to grasp;
- Propose a soft robotic EE that can handle the object at high-speed;
- Make a CAD design and insert the drawing; at least make a handwritten sketch;
- Submit a PDF file through **manaba+R**
- Submission deadline: **Jan. 12 (FRI), 23:55**