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Soft Robotics Lab.

Soft Robotics

Shinichi Hirai
Dept. Robotics, Ritsumeikan Univ.
http://www.ritsumei.ac.jp/~hirai/

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Schedule & Handouts

https://www.ritsumei.ac.jp/~hirai/edu/2026/soft_robotics/soft_robotics.html

Web lecture
10/9, 10/16, 10/23, 10/30, 11/6, 11/13

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Robots vs Creatures





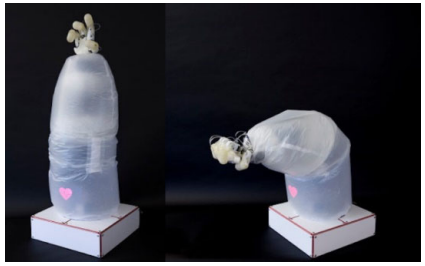
mainly hard materials
precise mechanism

hard and soft materials
loose mechanism

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Soft Robotics








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Soft Robotics

Soft robotics is a branch of robotics focused on creating mechanical systems from compliant, flexible materials like silicone, gels, and polymers, which allows them to deform, adapt, and safely interact with their environment, much like biological organisms. Unlike rigid robots, soft robots can operate in unstructured or delicate settings, manipulate fragile objects without damage, and perform complex, adaptive movements inspired by living creatures.

Soft Robot Features

Materials: soft, deformable materials, including elastomers, gels, and fluids.
Inspiration: inspired by biological structures, such as the movement of an octopus or a caterpillar.
Adaptability: conform to irregular shapes, adapt to different obstacles, and change their own shape to perform tasks.
Safety: inherently safer for human interaction and manipulation of delicate objects due to their compliance and reduced risk of damage.
Motion: complex and varied motions, including bending, twisting, and expanding, which are difficult for rigid machines.

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Soft Robot Potential Applications

Medical devices: For surgery, patient rehabilitation, and wearable health solutions.
Manipulation and gripping: Safely picking up delicate or irregularly shaped objects in manufacturing or logistics.
Locomotion: Moving through complex environments, like uneven terrain or narrow spaces.
Wearable technology: Creating comfortable and adaptive devices for human use.

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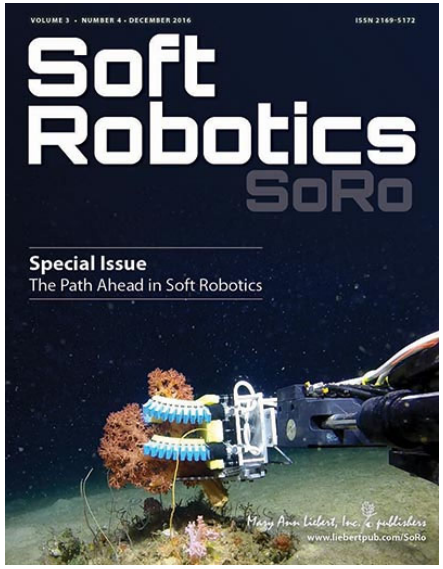
Soft Robotics Activities



SIG Soft Robotics

Special Interest Group on Soft Robotics

新学術領域「ソフトロボット学」
Science of Soft Robot



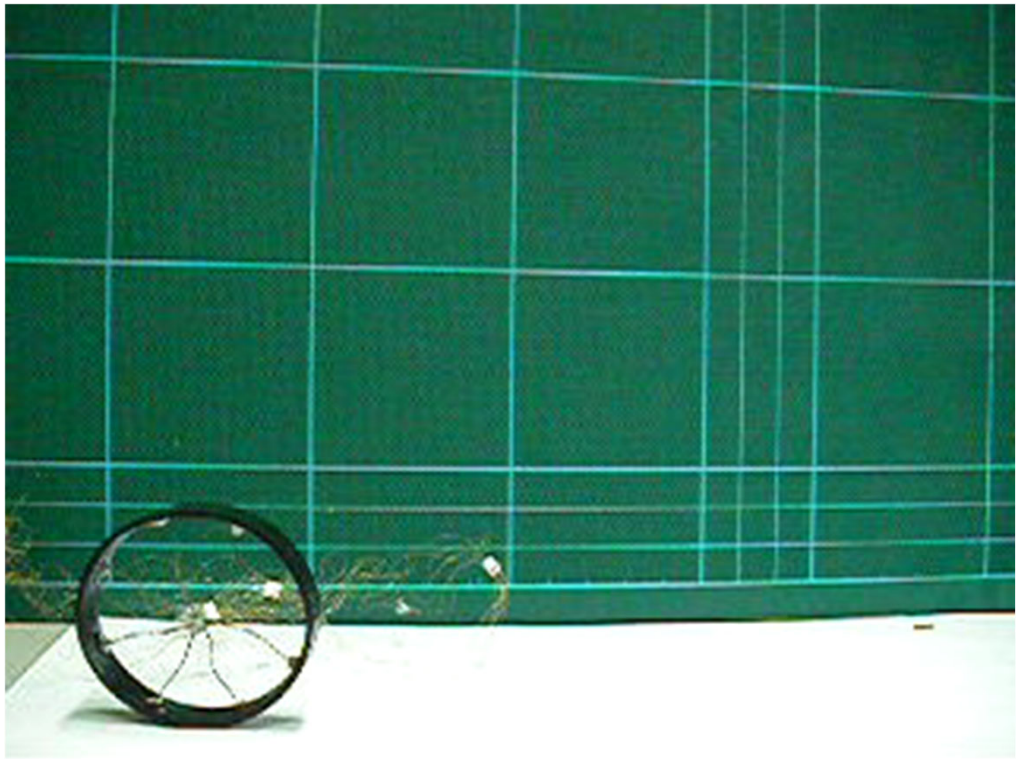
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IEEE Int. Conf. on Soft Robotics



The First RoboSoft, Livorno, Italy, 2018

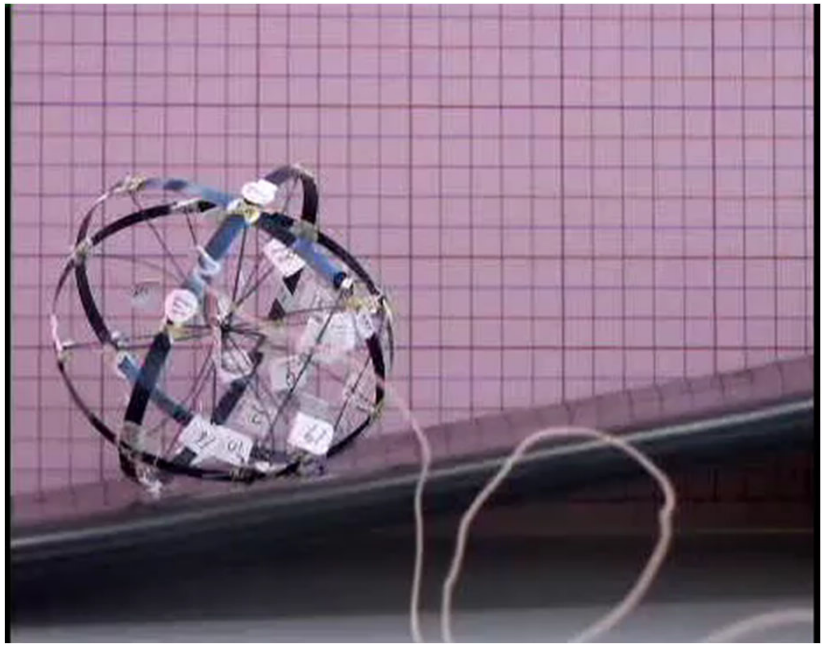
Circular Soft Robot

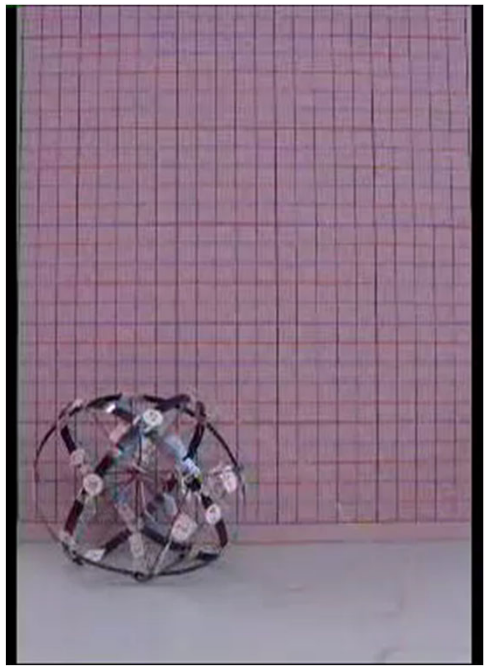


Sugiyama and Hirai, Crawling and Jumping by a Deformable Robot, IJRR, 25-5/6, 603-620, 2006

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Spherical Soft Robot

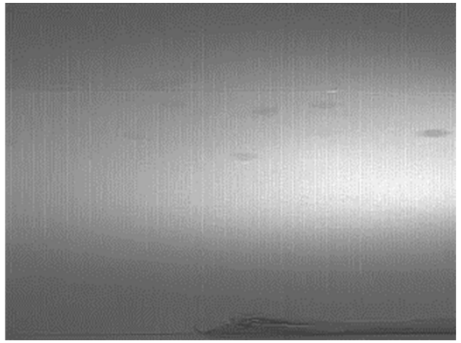
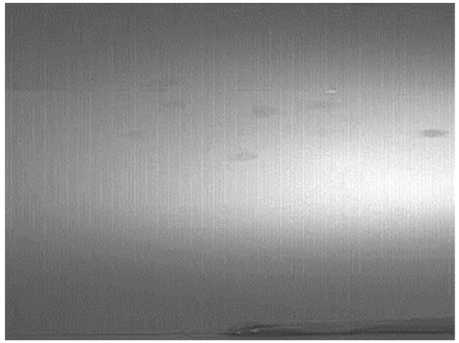
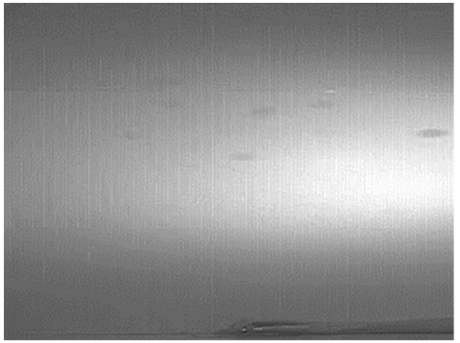




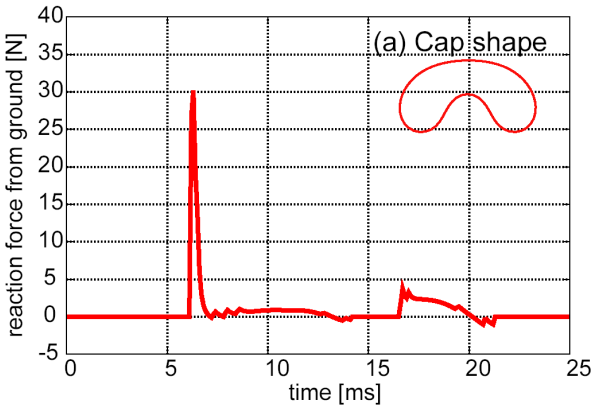
Sugiyama and Hirai, Crawling and Jumping by a Deformable Robot, IJRR, 25-5/6, 603-620, 2006

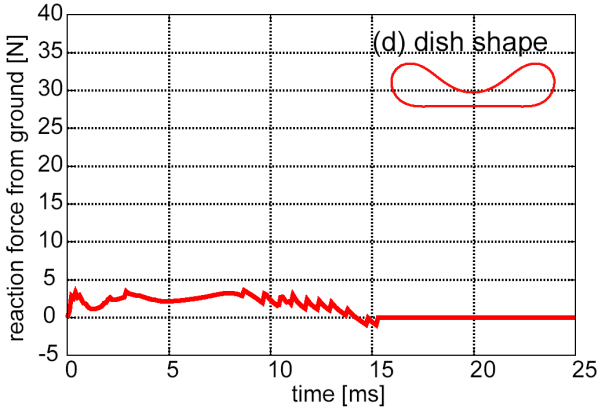
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Soft Robot Jumping

Cap 
Cup 
Peanut 
Dish 

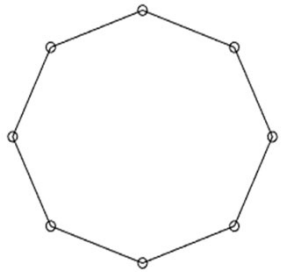




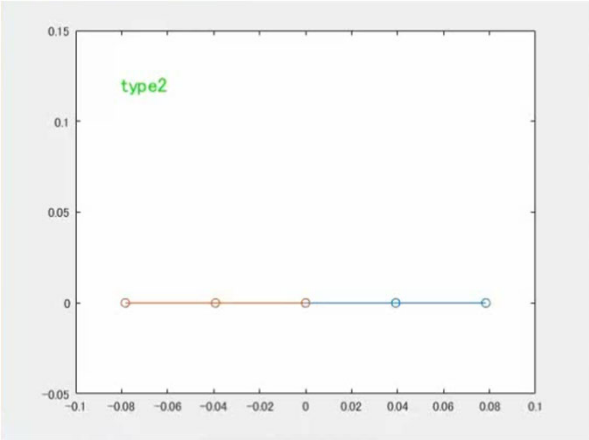
Matsuyama and Hirai, IEEE ICRA, 2007

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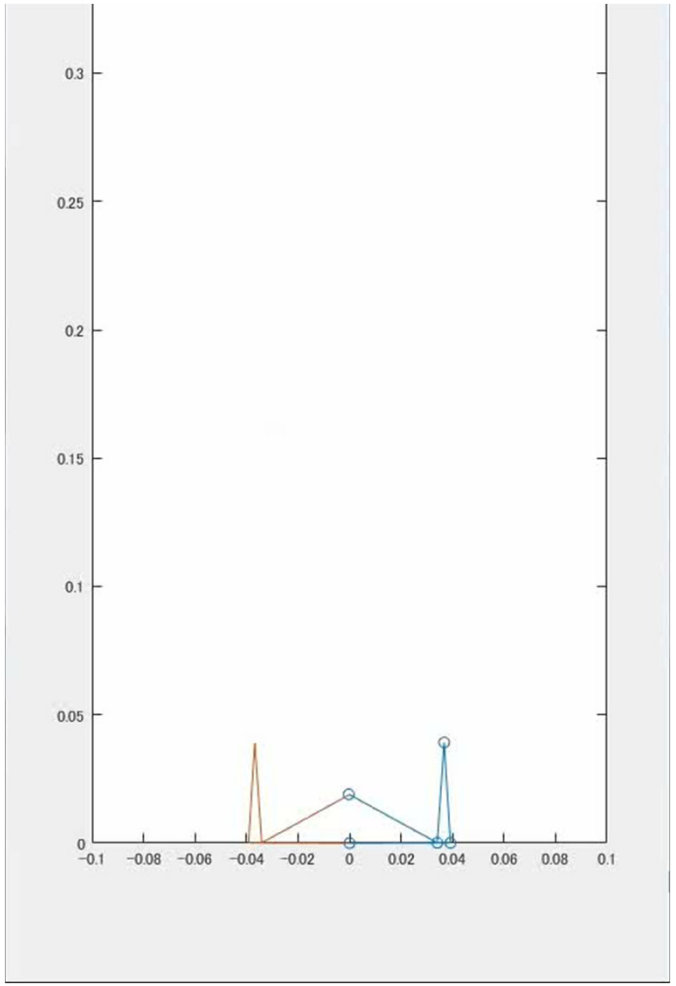
Soft Robot Jumping



soft robot model



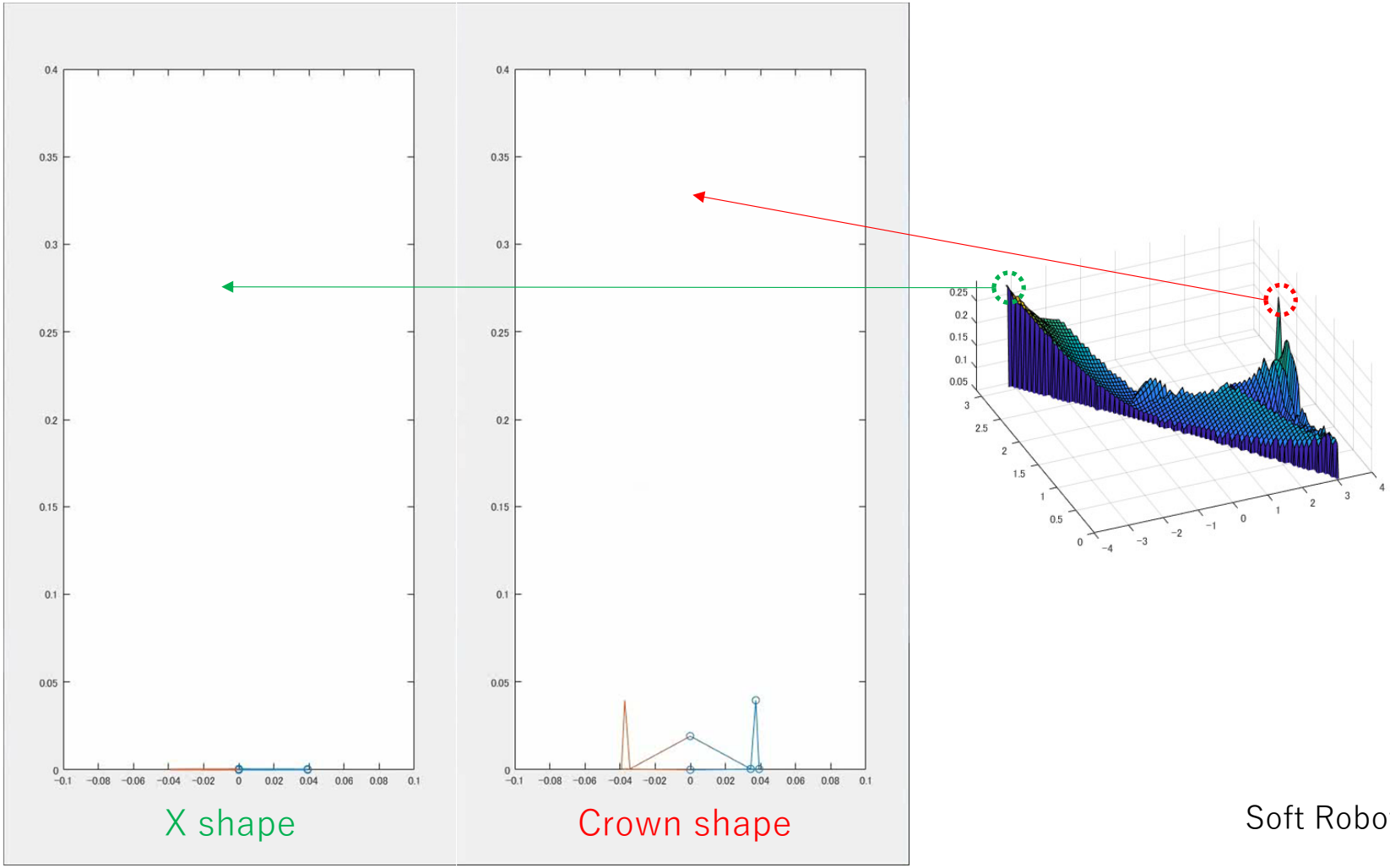
calculation process



Matsuno and Hirai, RoboSoft 2020

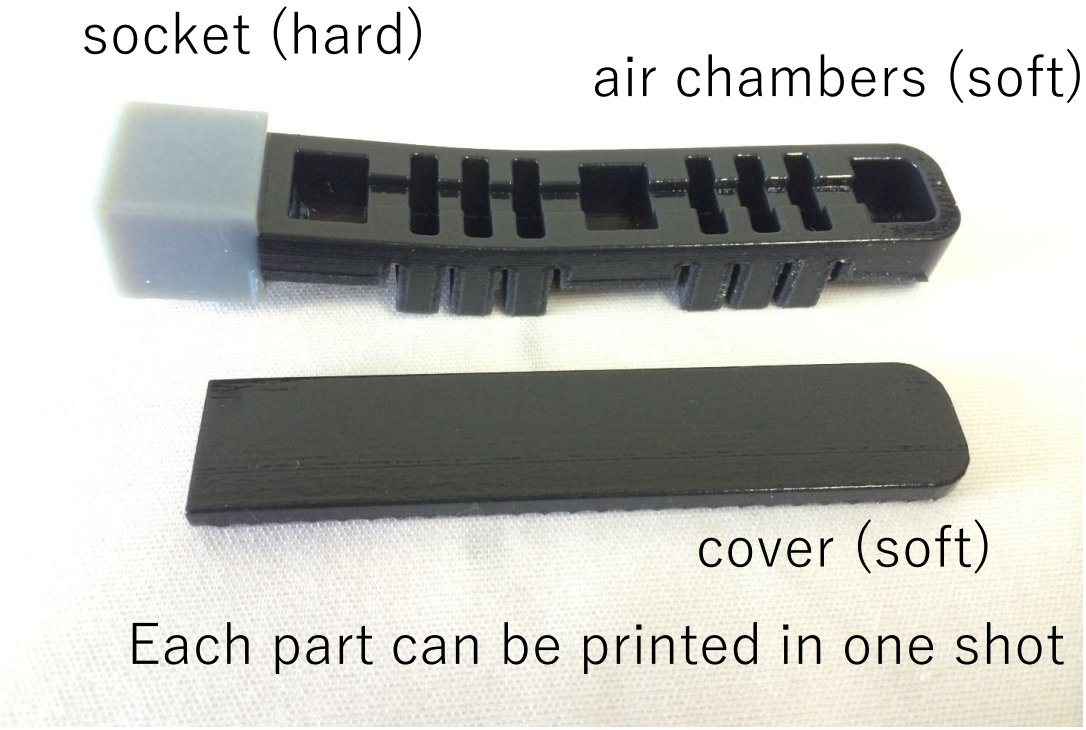
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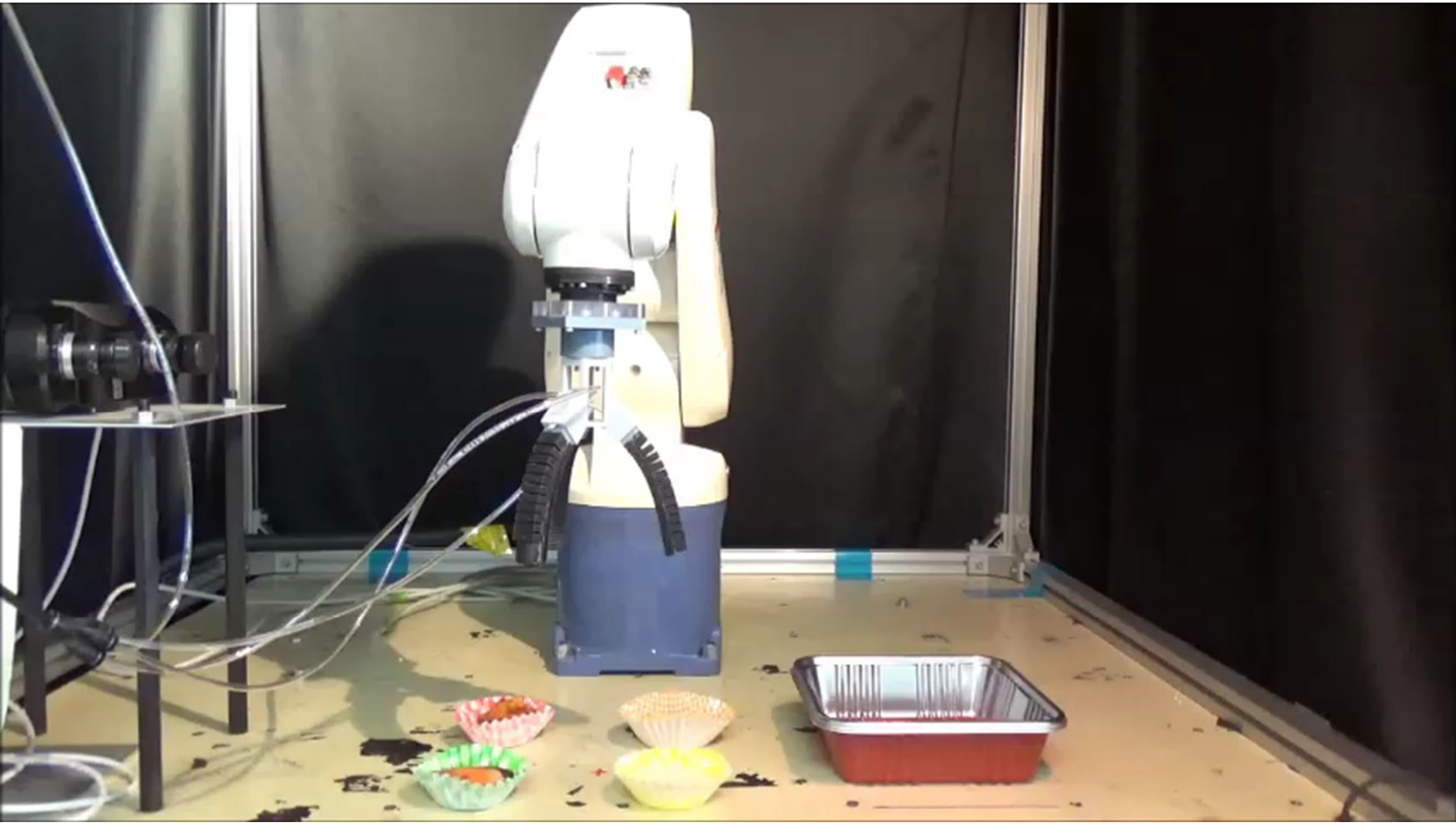
Soft Robot Jumping



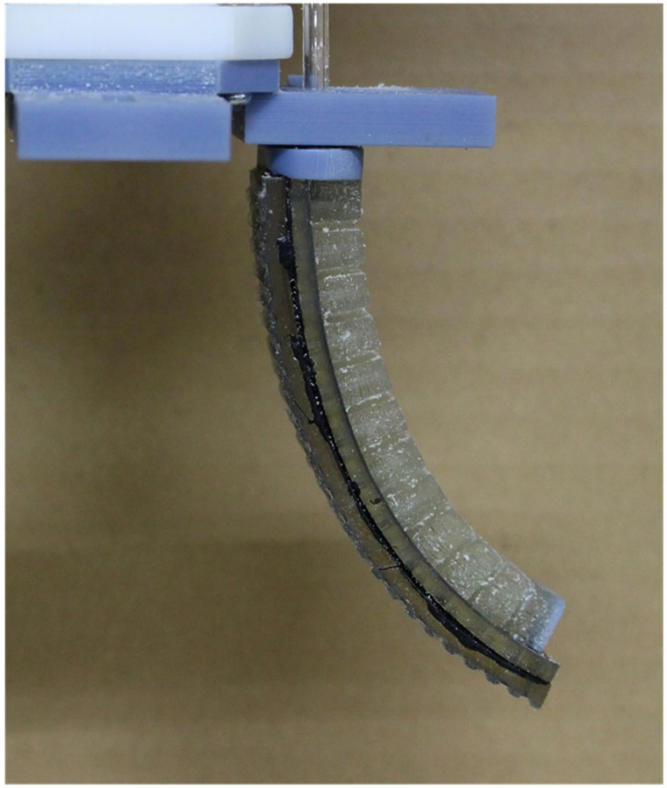
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Soft Bendable Fingers

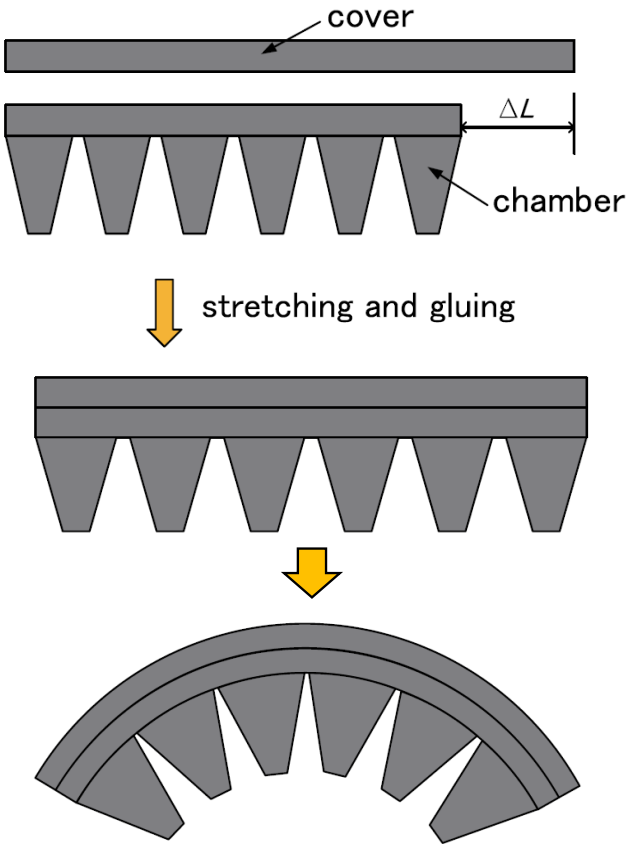




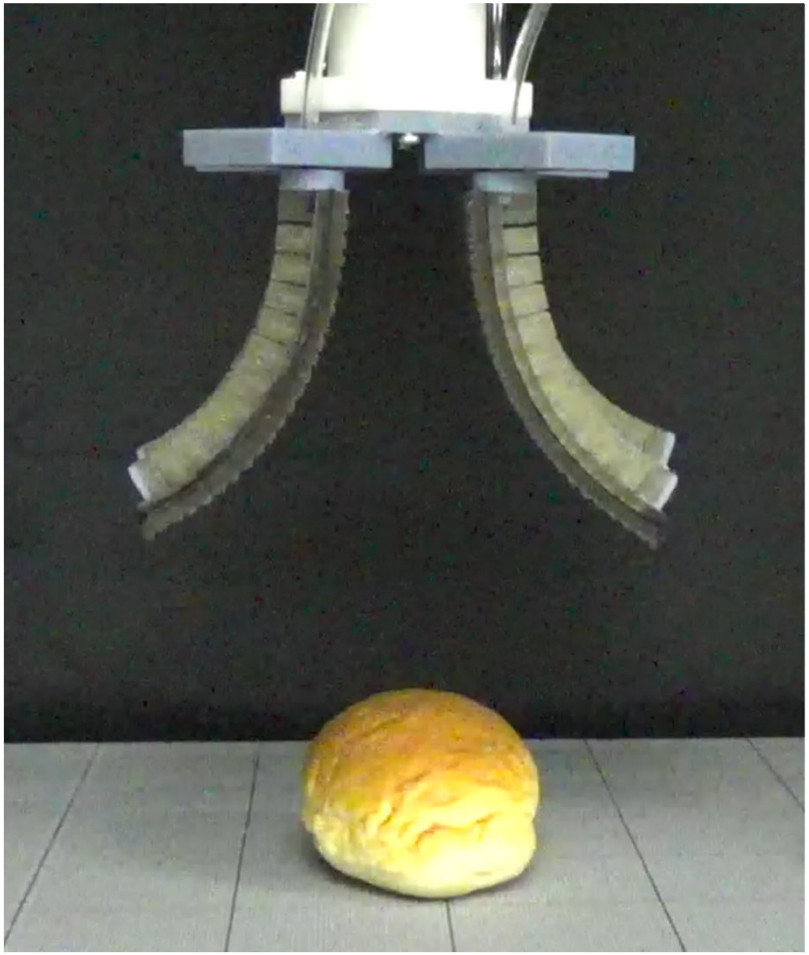
Soft Bendable Fingers

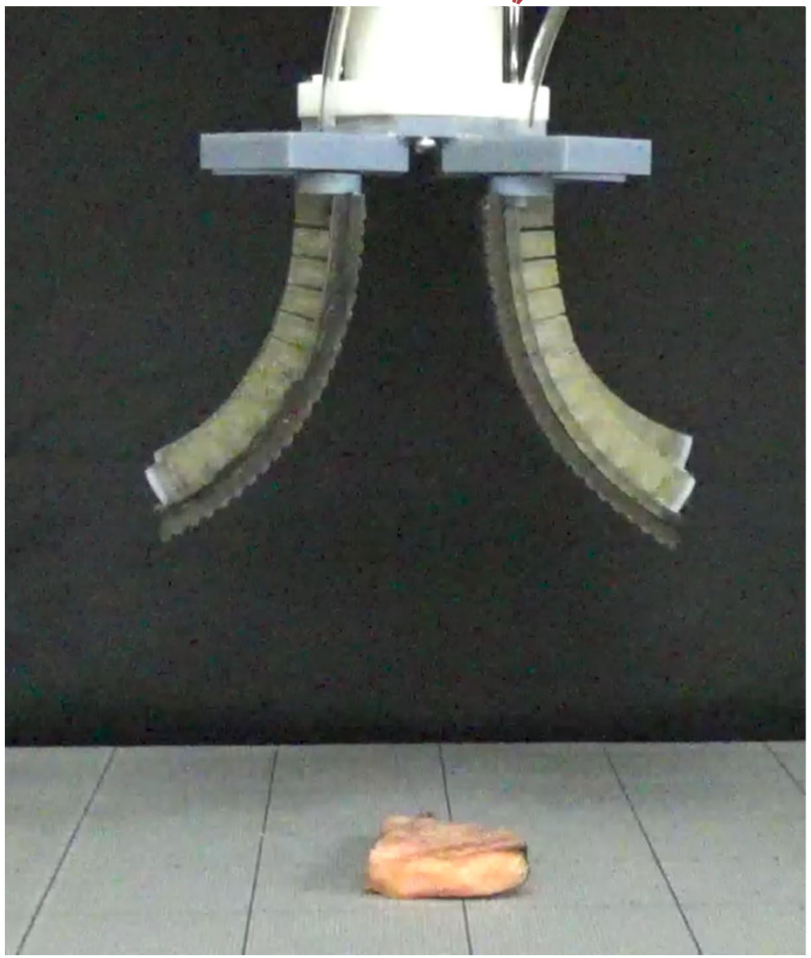


Wang et al., IEEE RAL, 2017



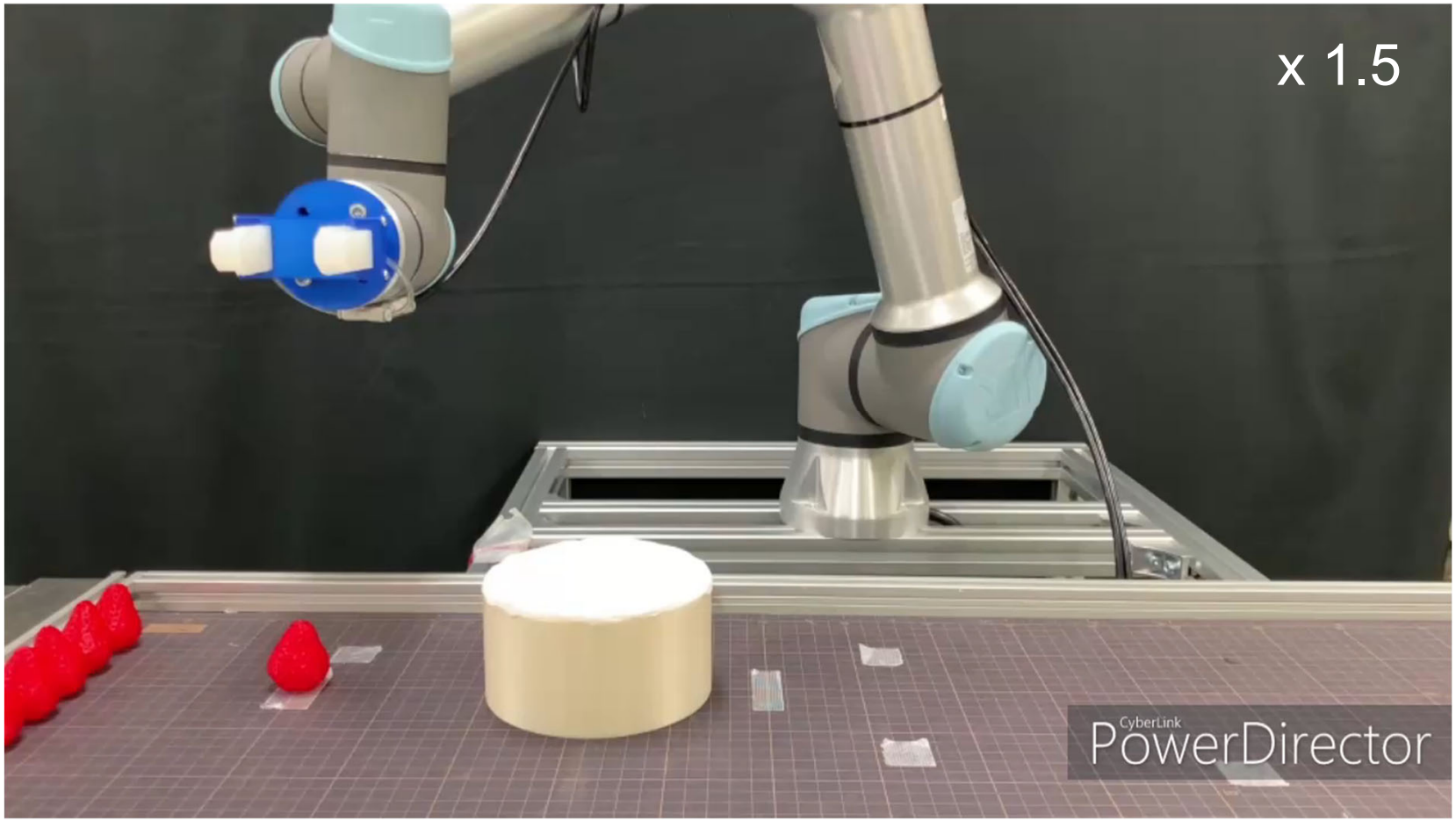
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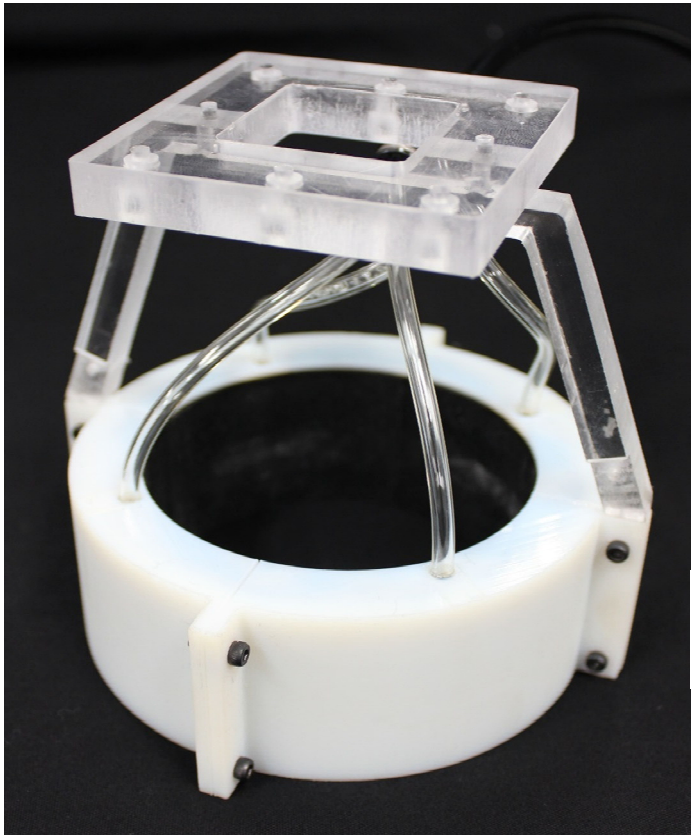
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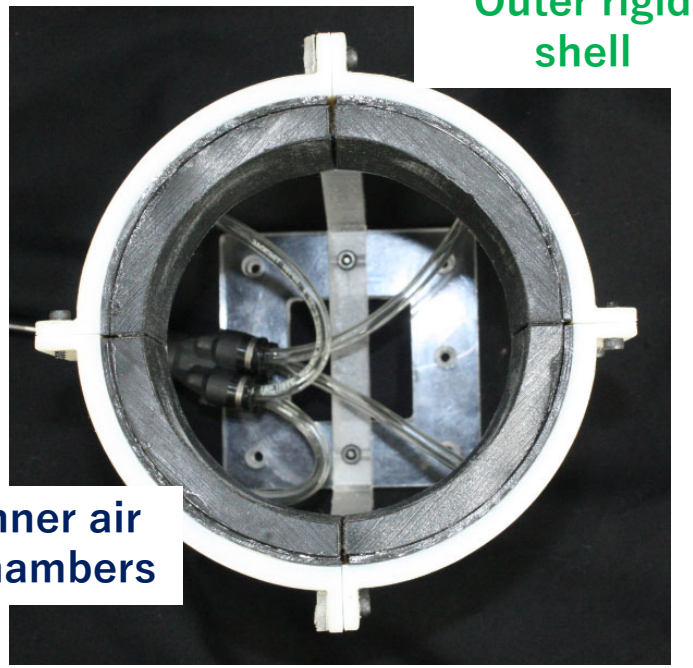
Manipulating Delicate Objects

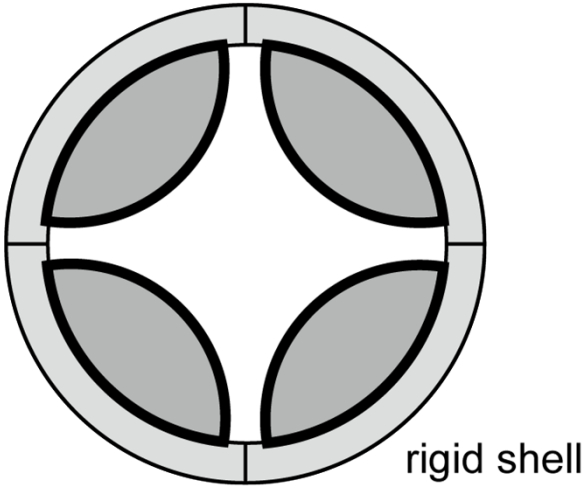


Matsuno et al., IEEE/SICE SII 2024

Expanding Membrane Hand

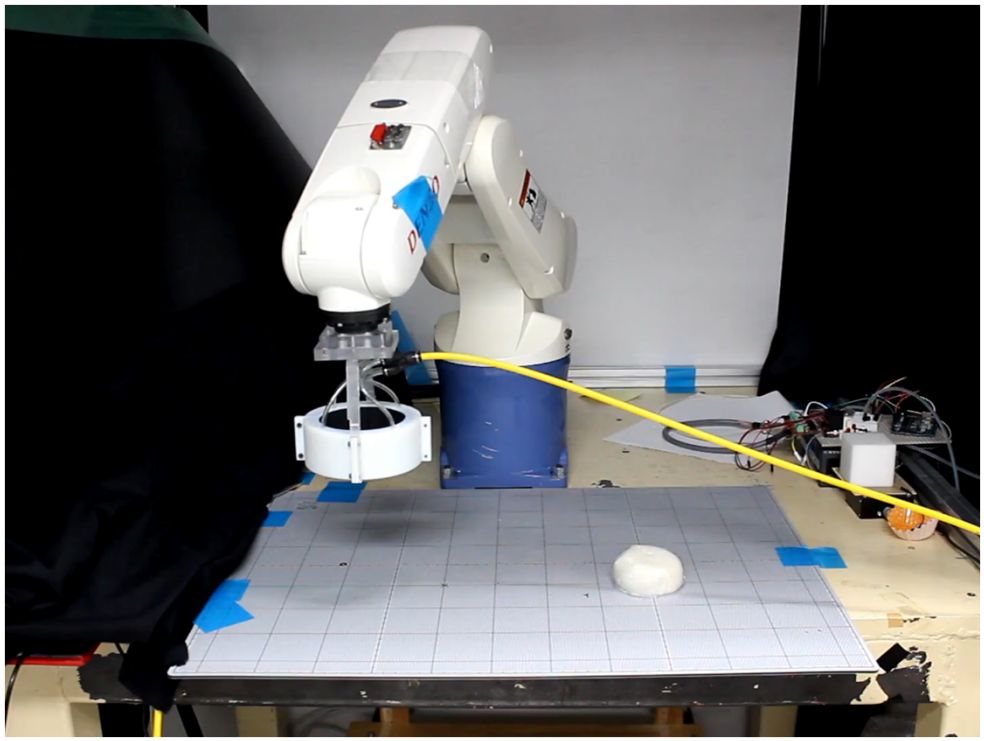


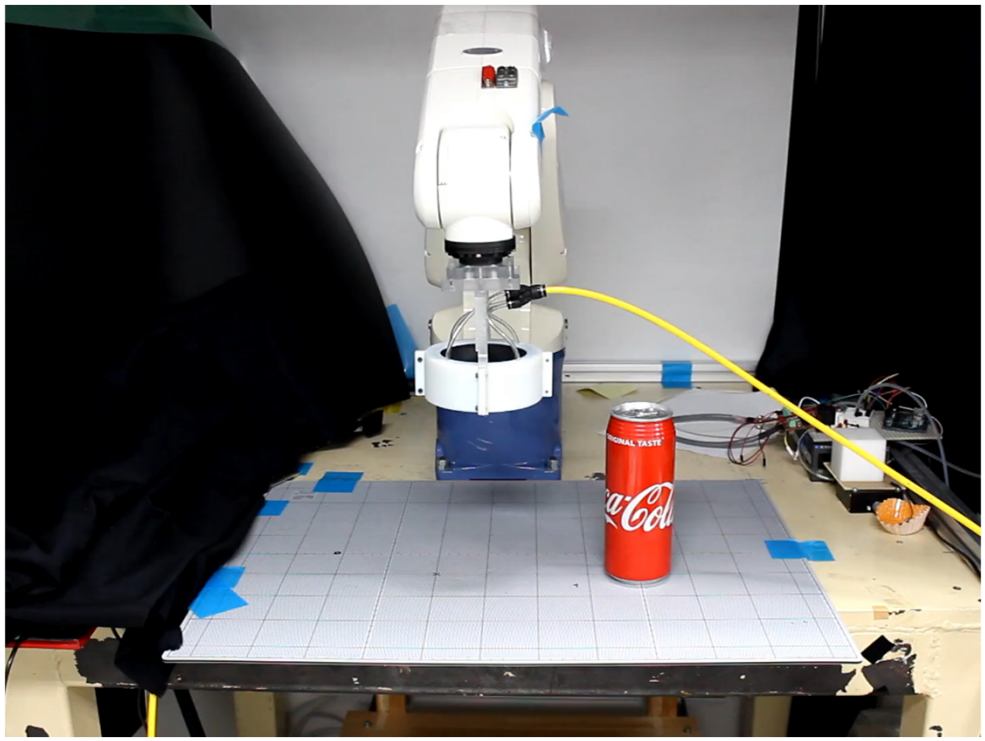




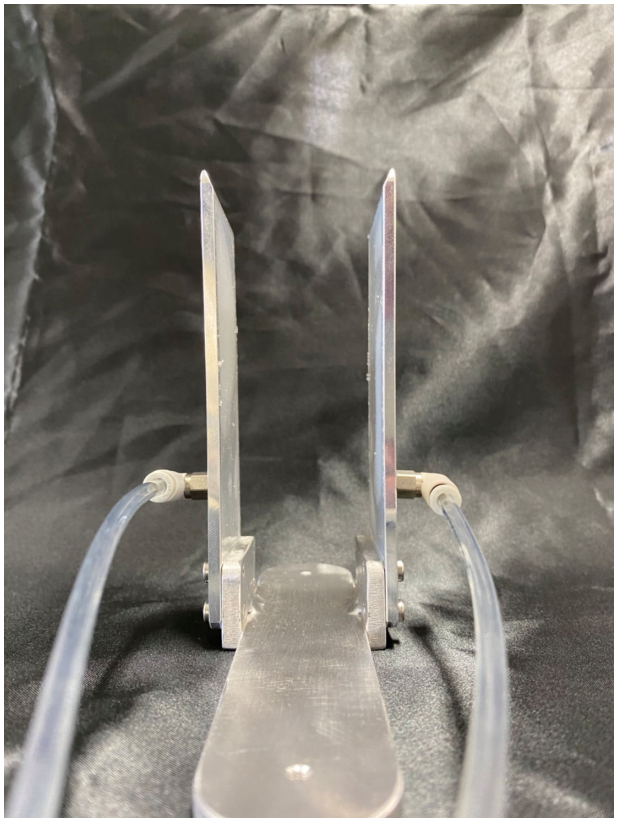
Wang, Kanegae, and Hirai, Circular Shell Gripper for Handling Food Products, Soft Robotics, 2020

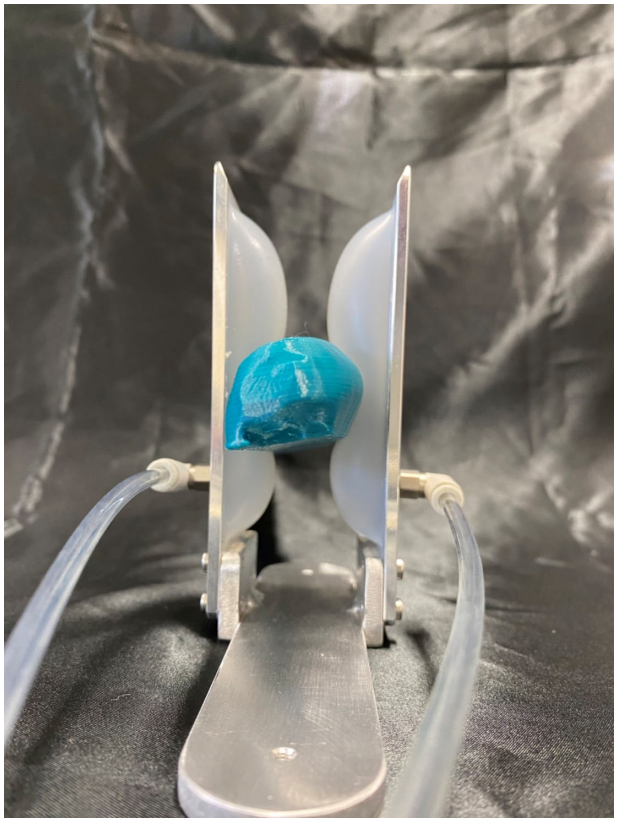
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Application to Agriculture



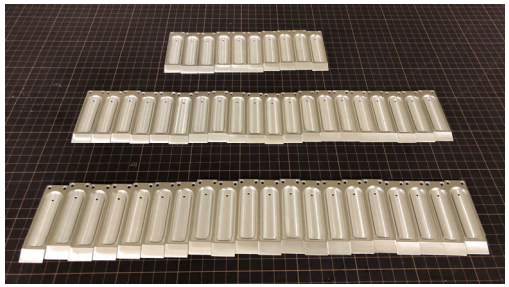


Aoyama et al., Shell Gripper Inspired by Human Finger Structure for Automatically Packaging Agricultural Product, Humanoids 2022

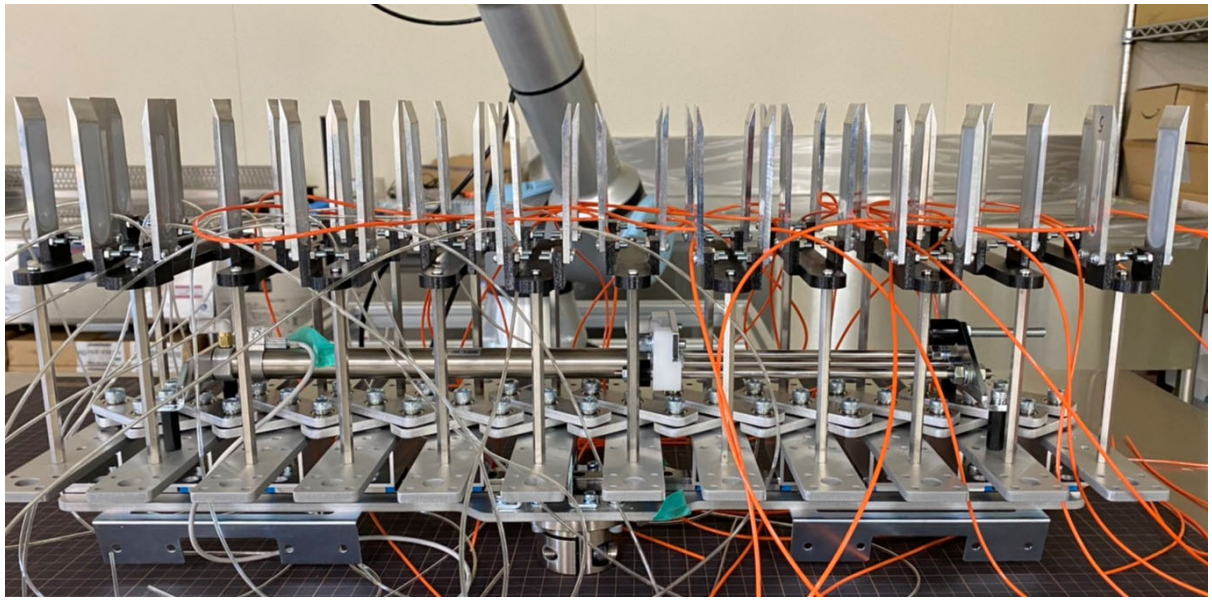
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Application to Agriculture









Simultaneous grasping of multiple cucumbers

Aoyama et al., Shell Gripper Inspired by Human Finger Structure for Automatically Packaging Agricultural Product, Humanoids 2022


Aoyama et al., IEEE Humanoids 2022

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Fabric Manipulation







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Motivation



https://vn-bizmatch.com/vietnamese-35/



https://www.temjin-tv.com/works/2023/09/27/2561/

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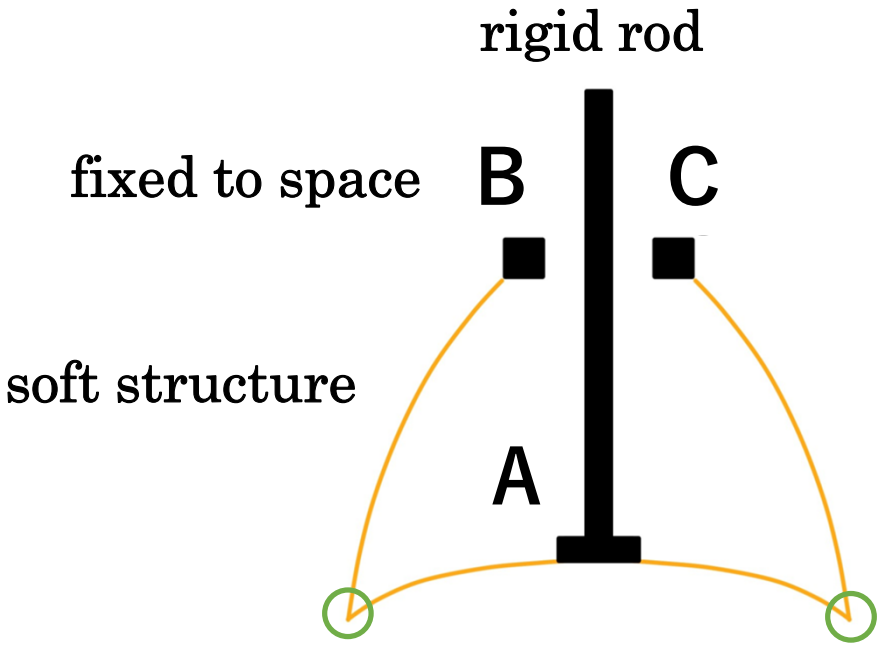
Principle

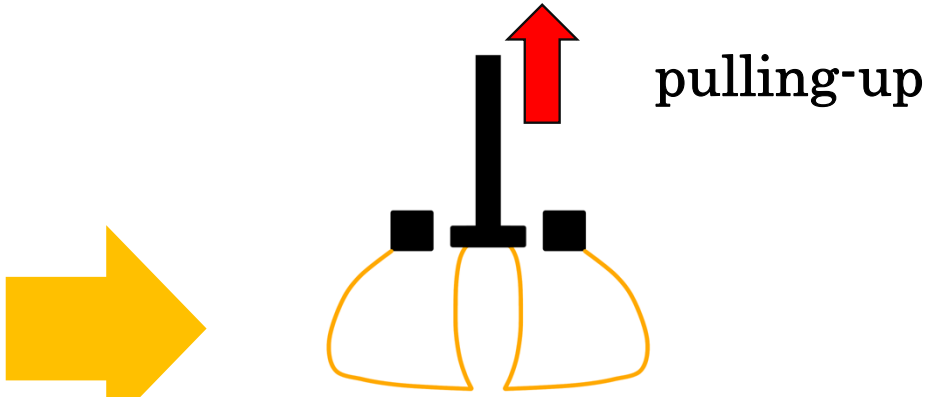


- soft fingertips contacting with a fabric
- large friction between fingertips and the fabric
- fingertips moving along the fabric

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Pulling-Driven Soft Hand





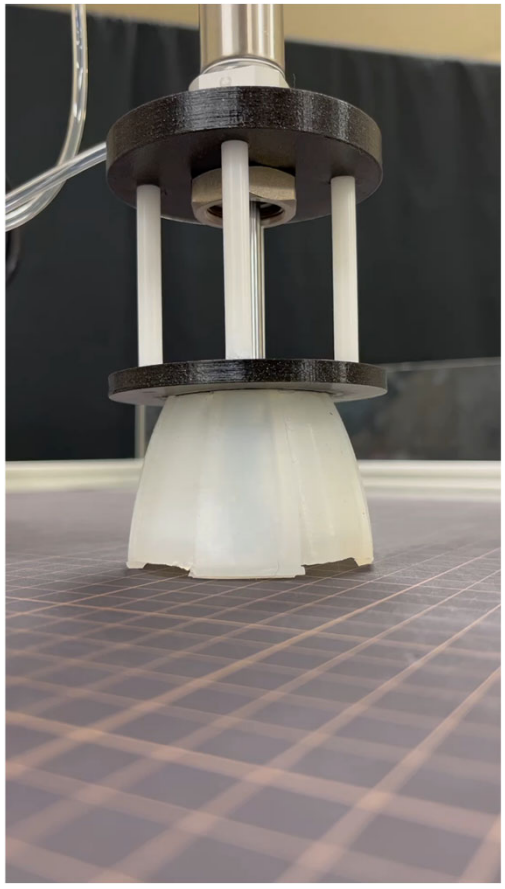
Hanamura et al, IEEE/SICE SII 2024

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Pulling-Driven Soft Hand

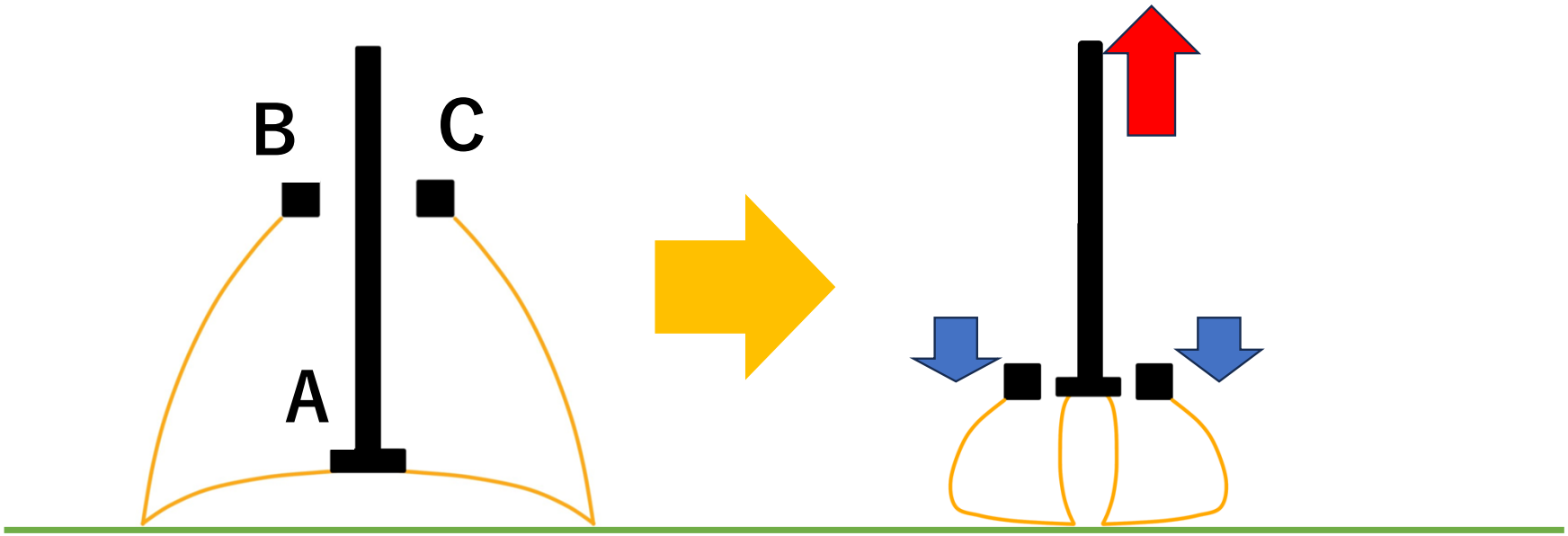








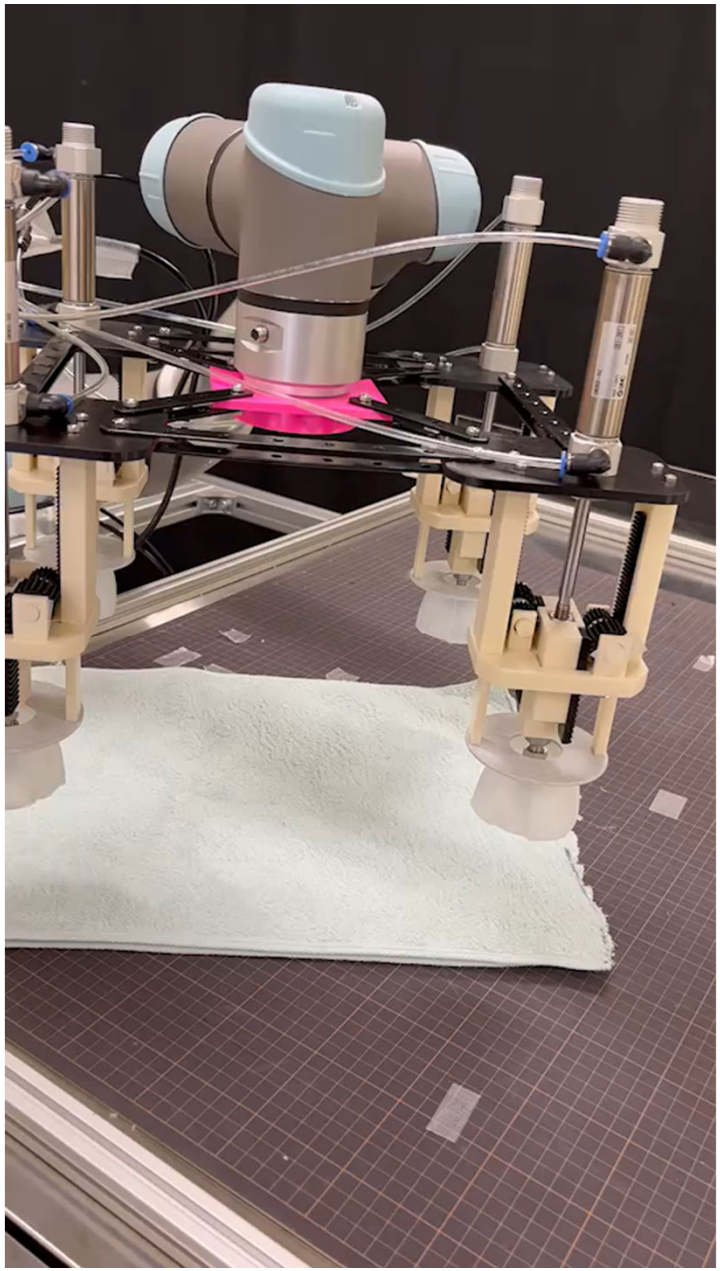
Closing-Approaching Coupling



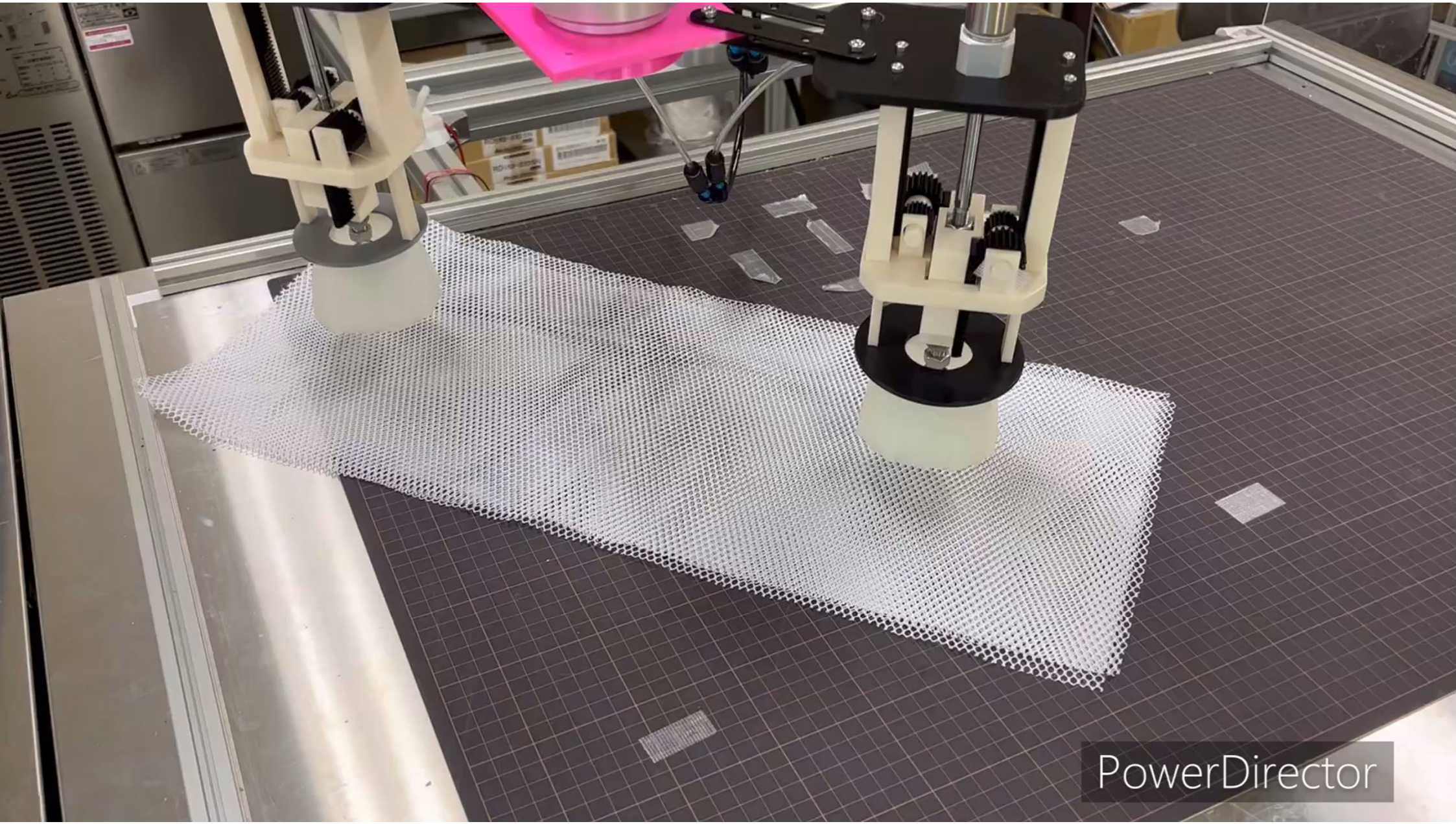
Hanamura et al, IEEE/SICE SII 2024




CyberLink
PowerDirector






PowerDirector

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Living Organism Manipulation





https://job.fishermanjapan.com/column/3042/

https://mainichi.jp/articles/20200217/k00/00m/040/024000c

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Motivation





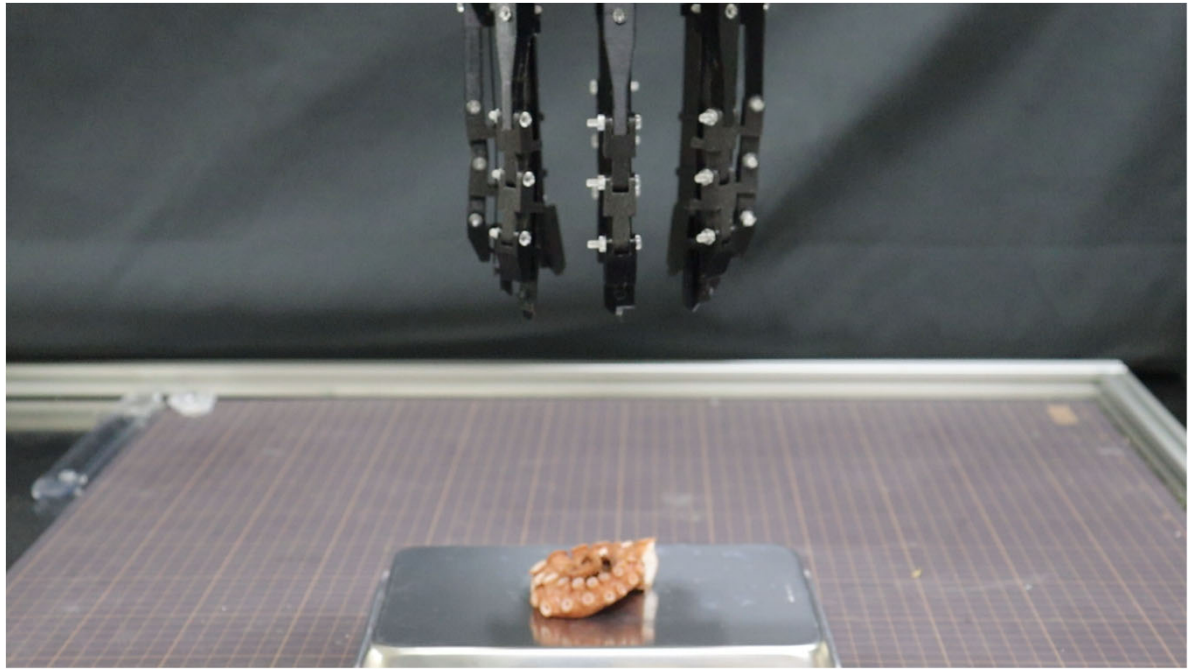
Grasping and manipulation of underwater organisms
Electricity in water may cause problems
→ Non-electric hands

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Contact-driven Hand

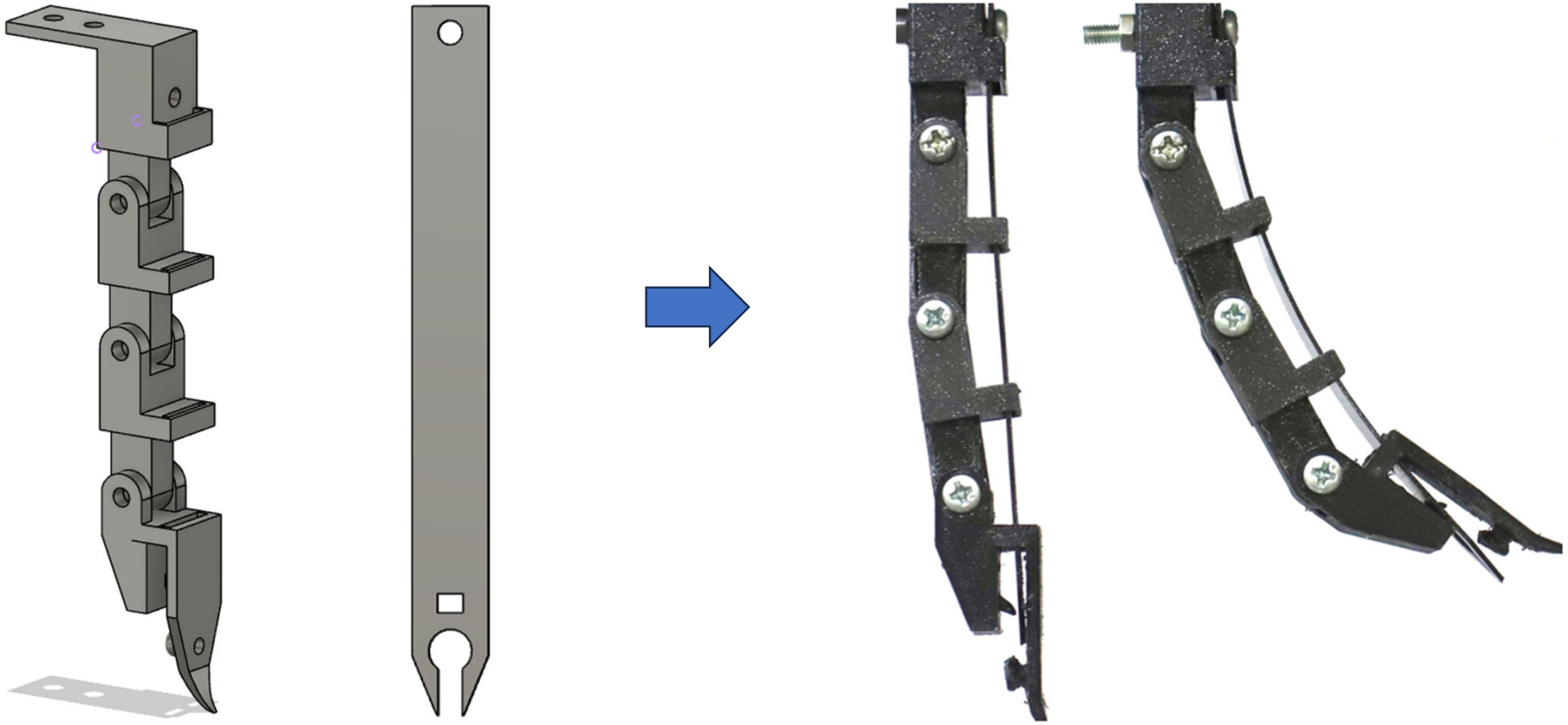
Grasping of benthos ←
Opening/closing via contact force

Nate et al., IEEE ICRA 2023



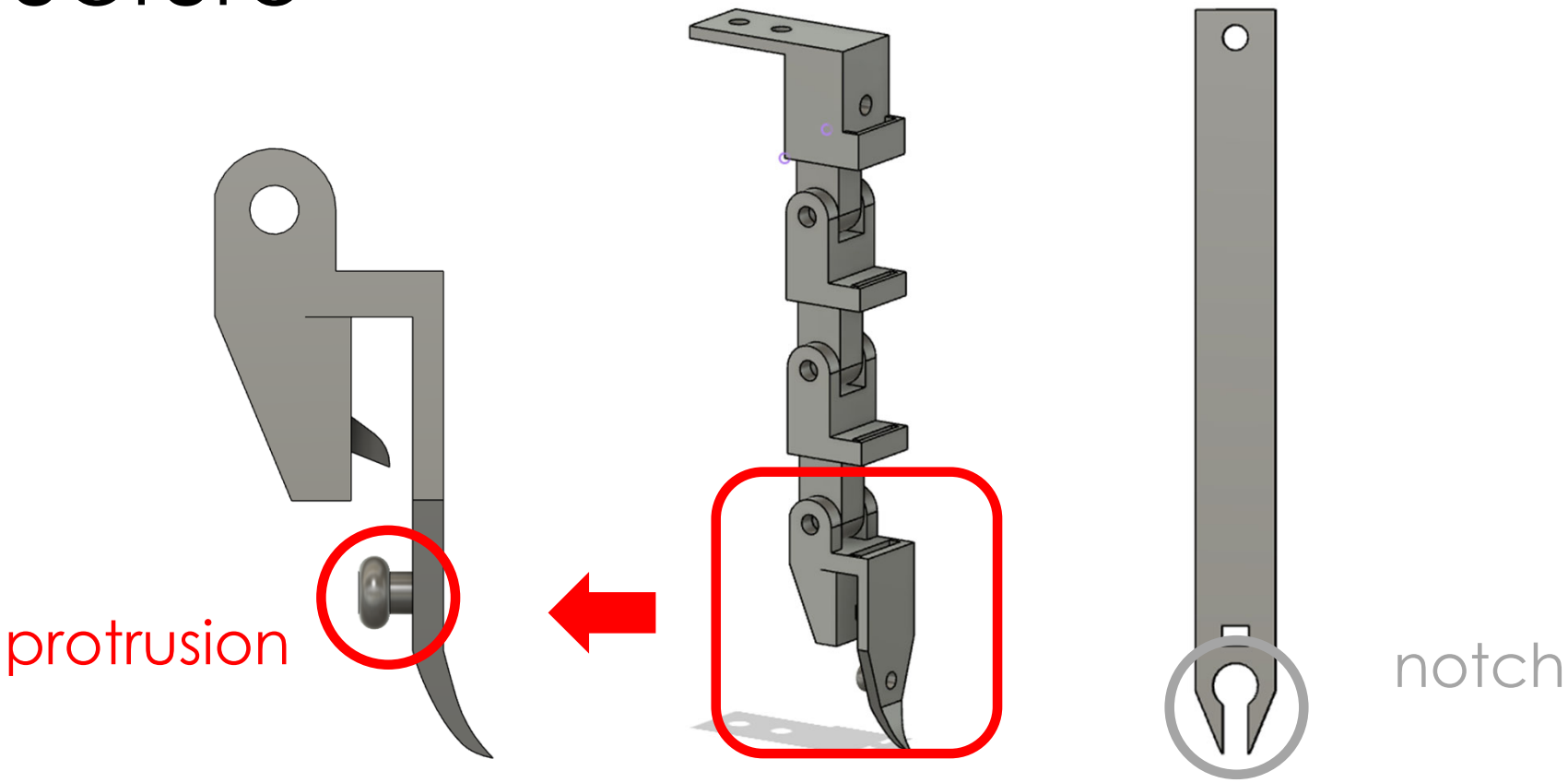
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Structure



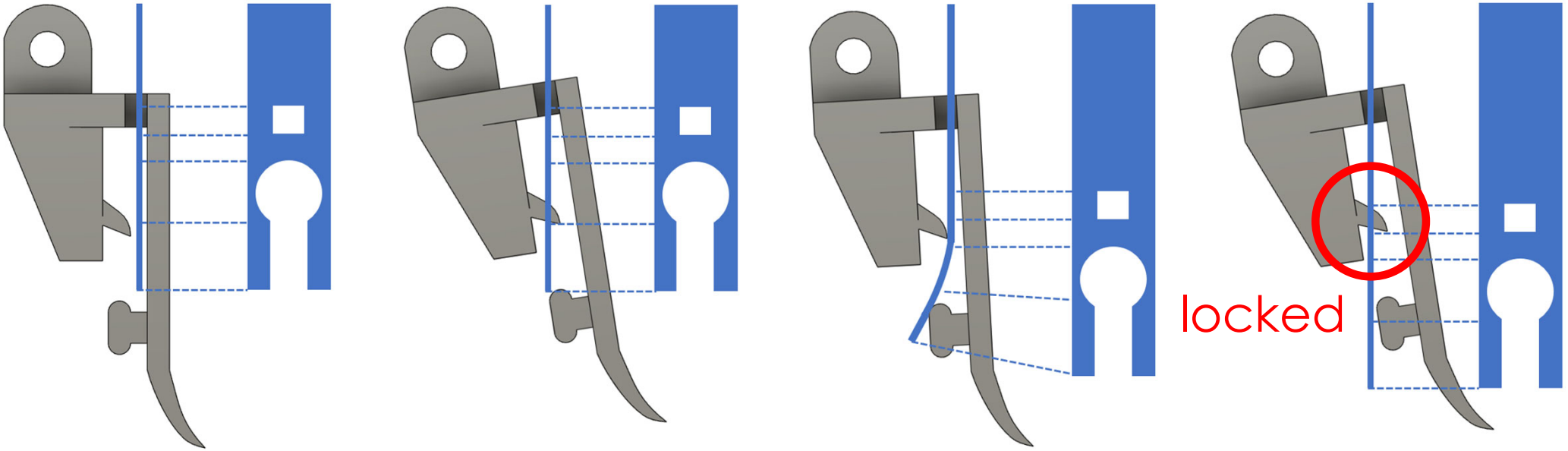
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Structure



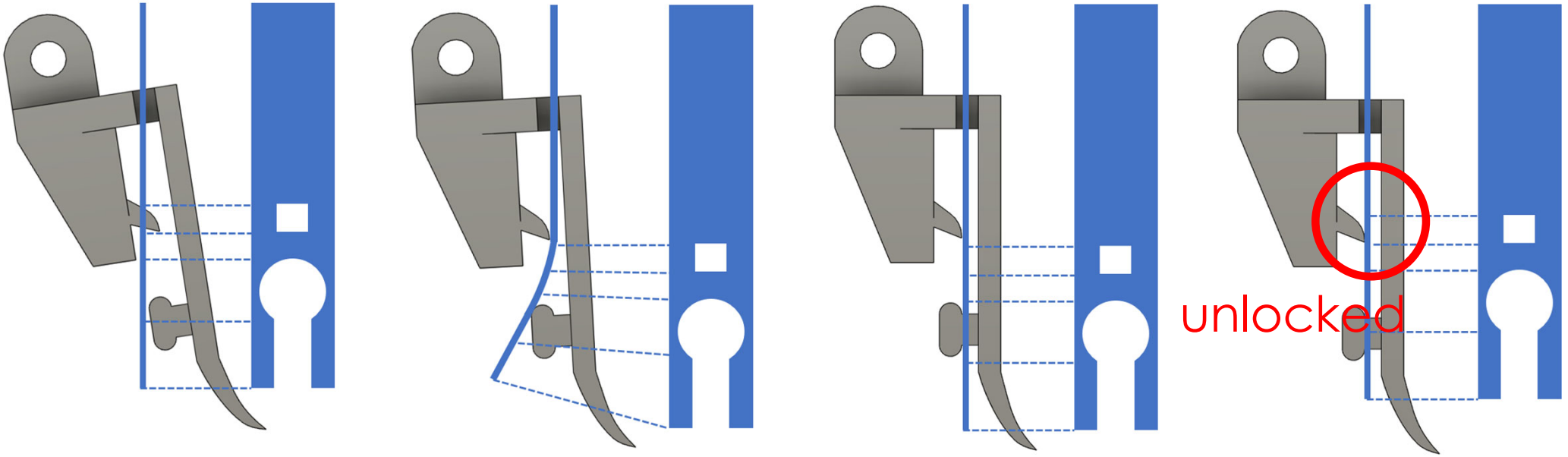
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Locking via contact force



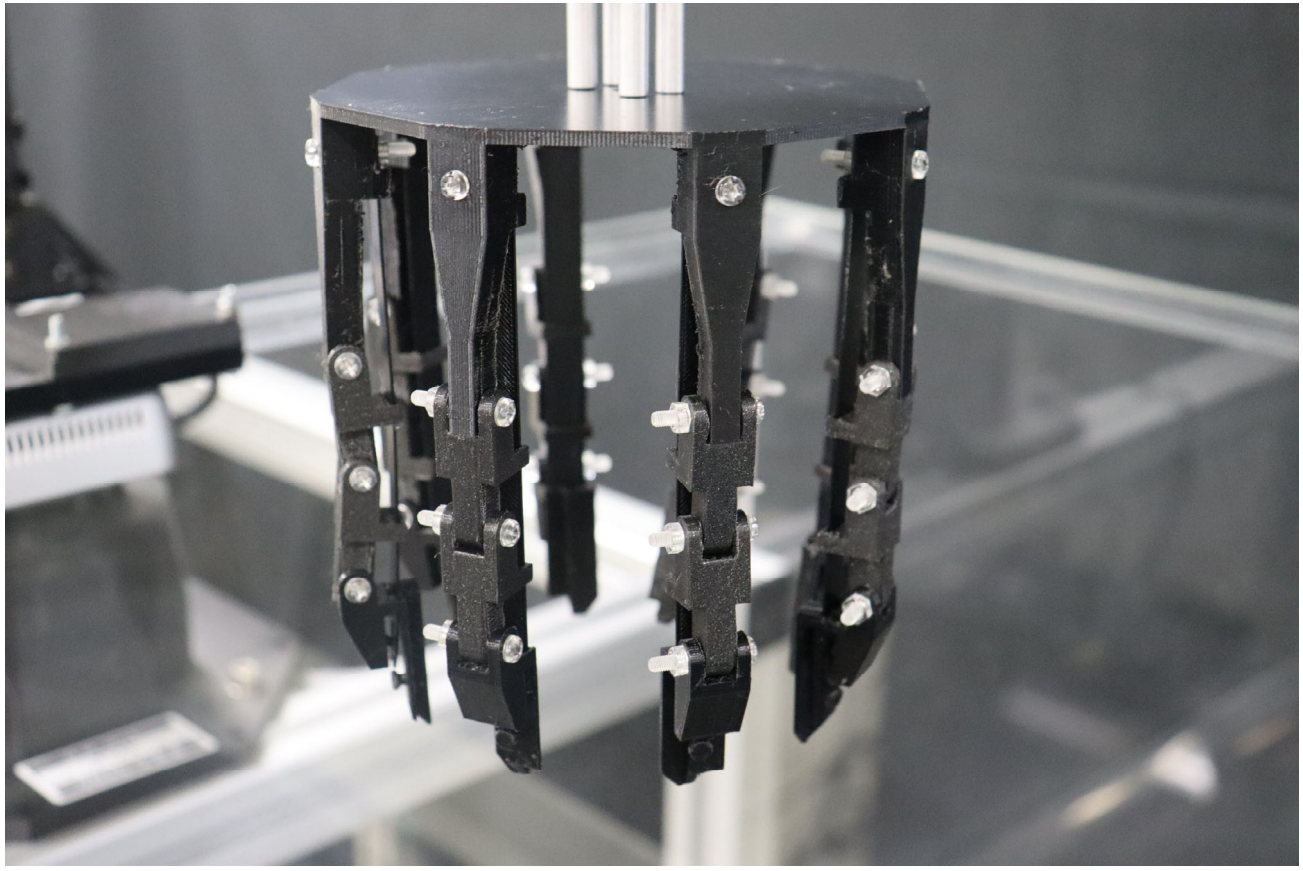
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Unlocking via contact force



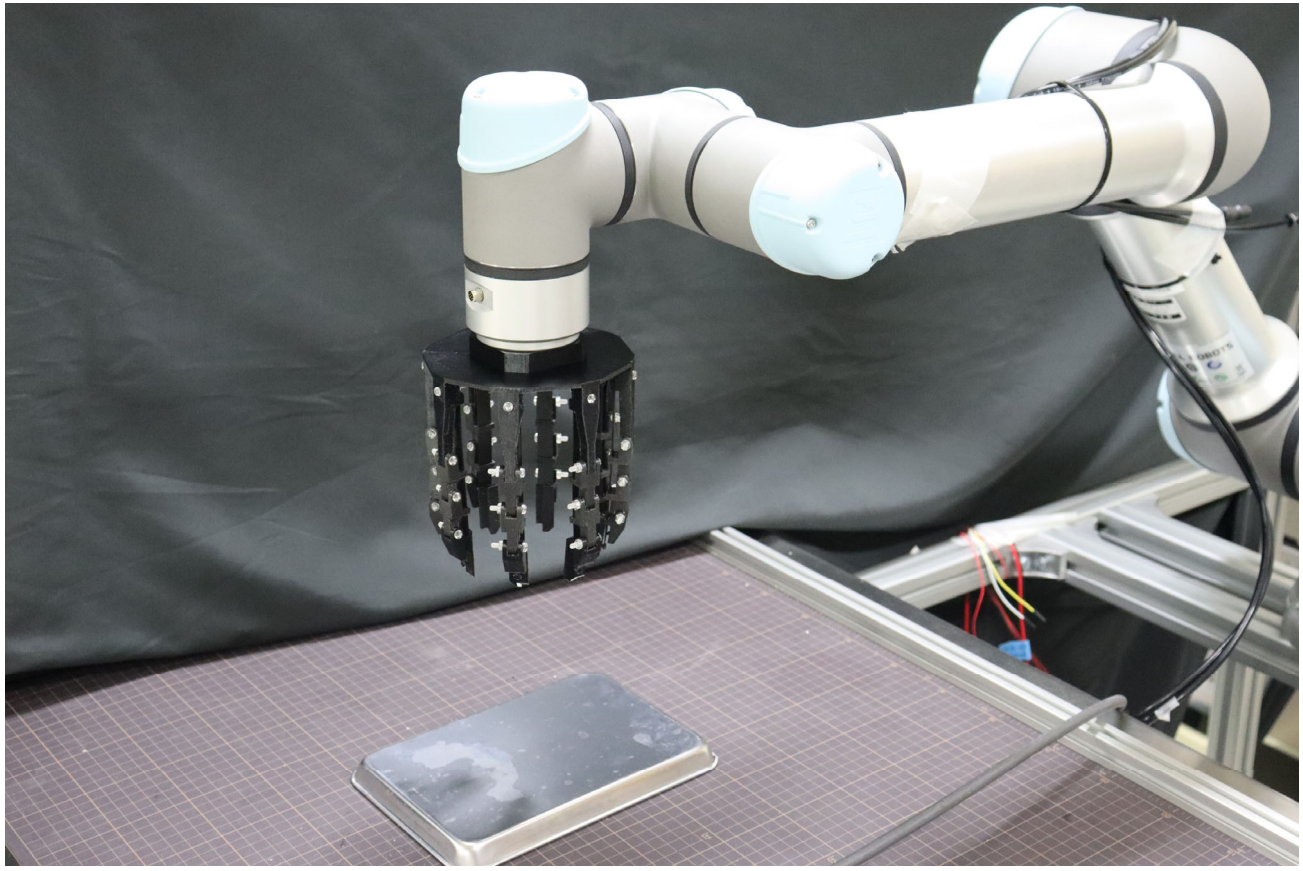
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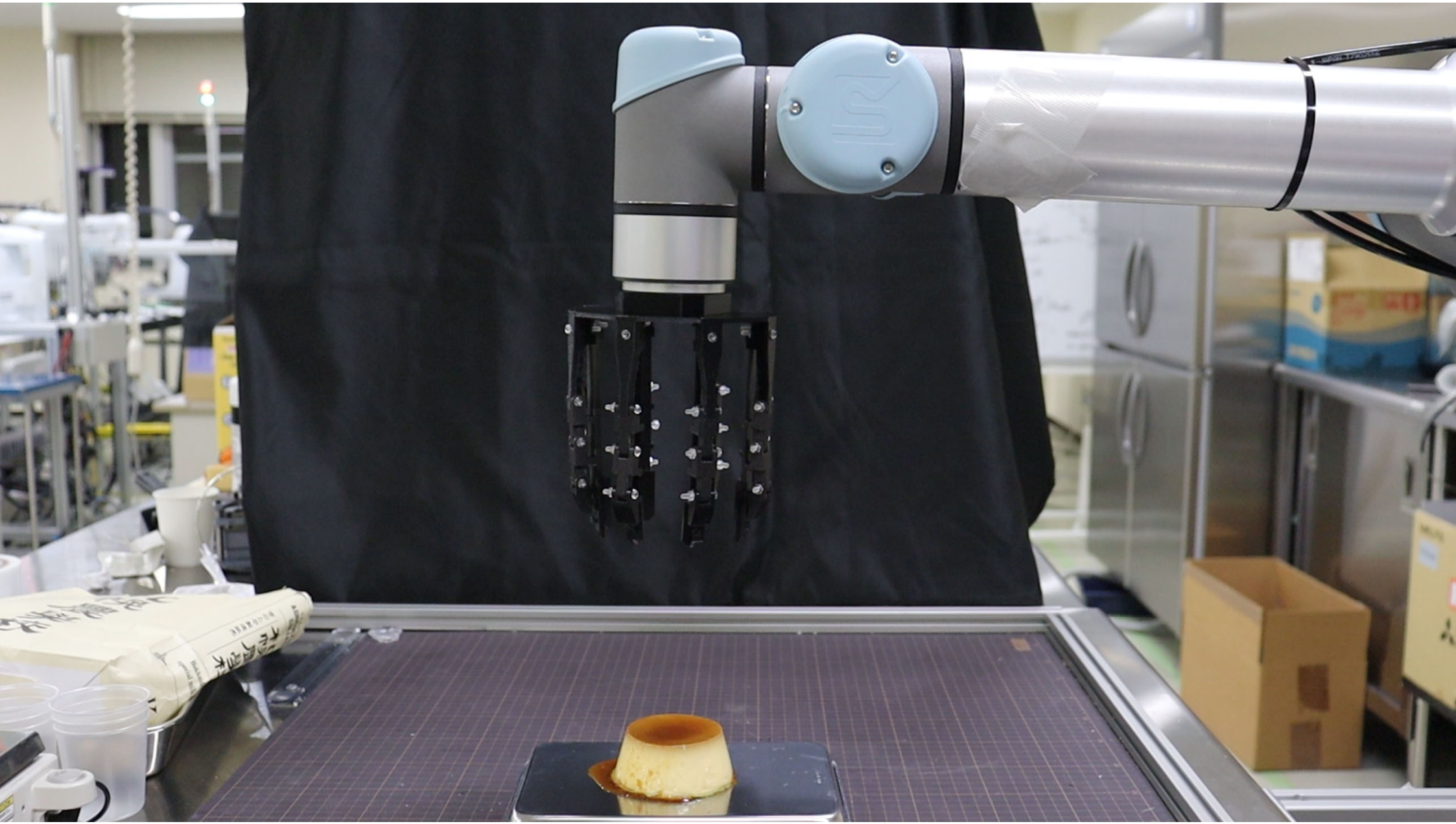
Hand

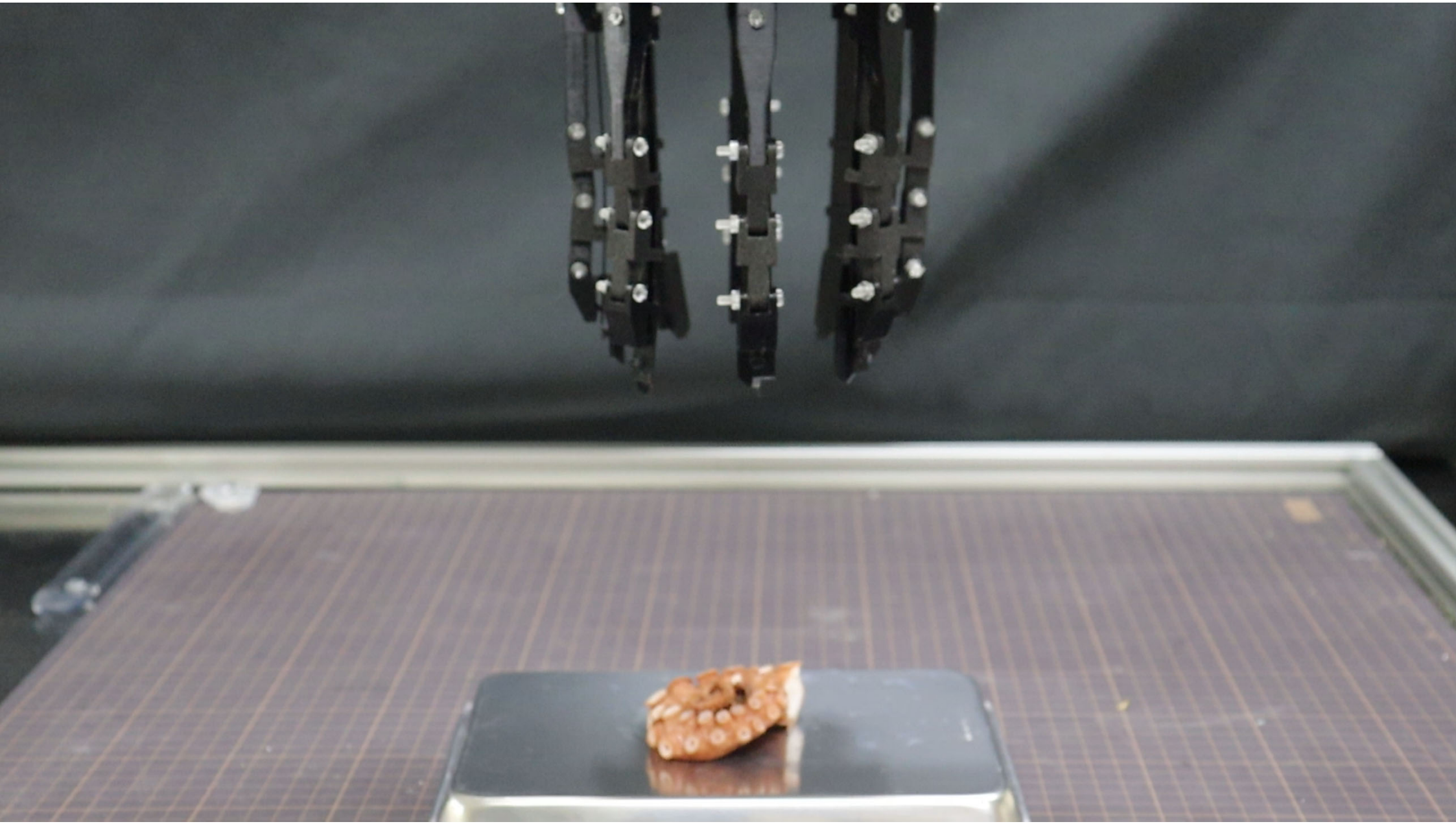




Experiments

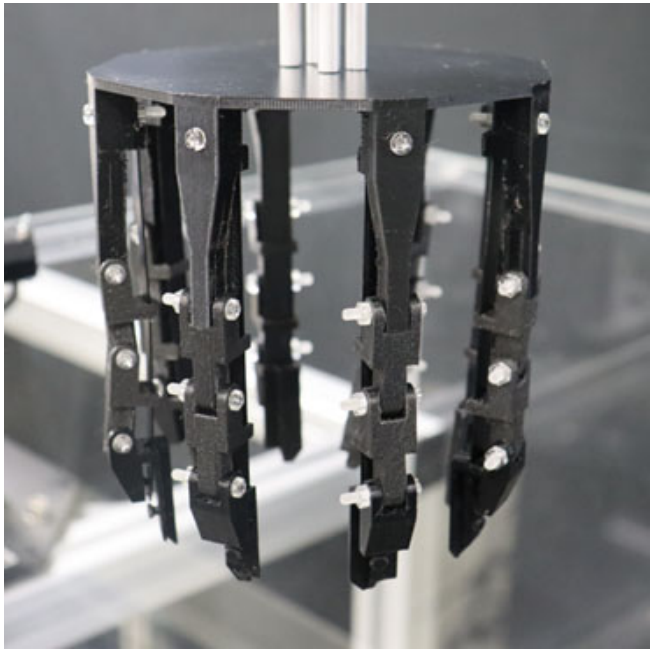




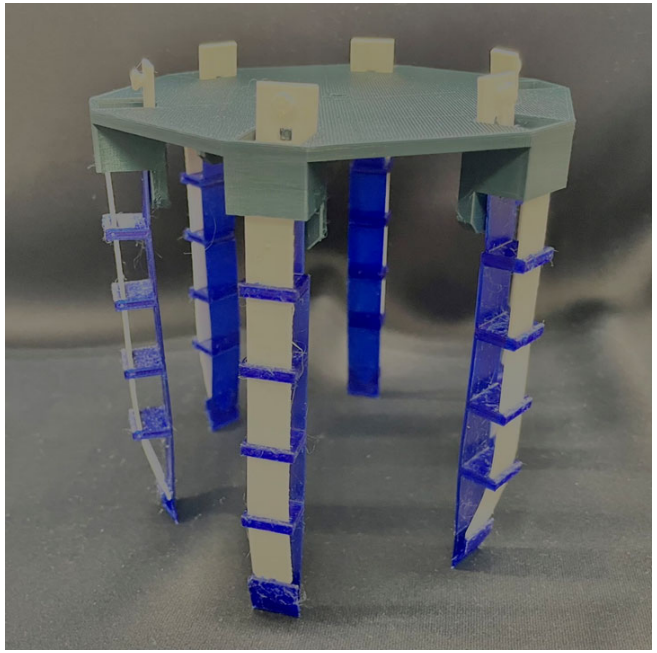


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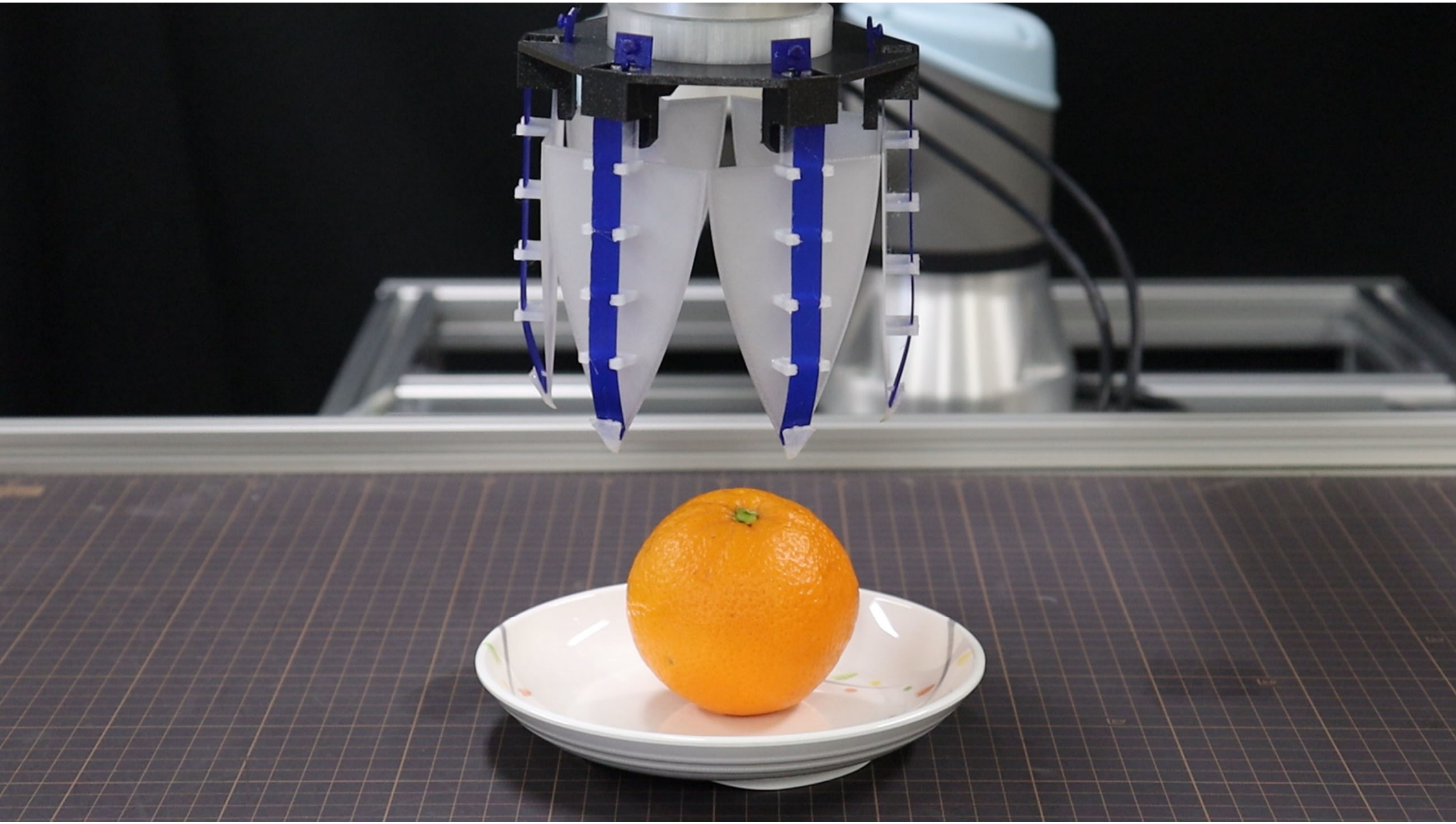
Simplified finger

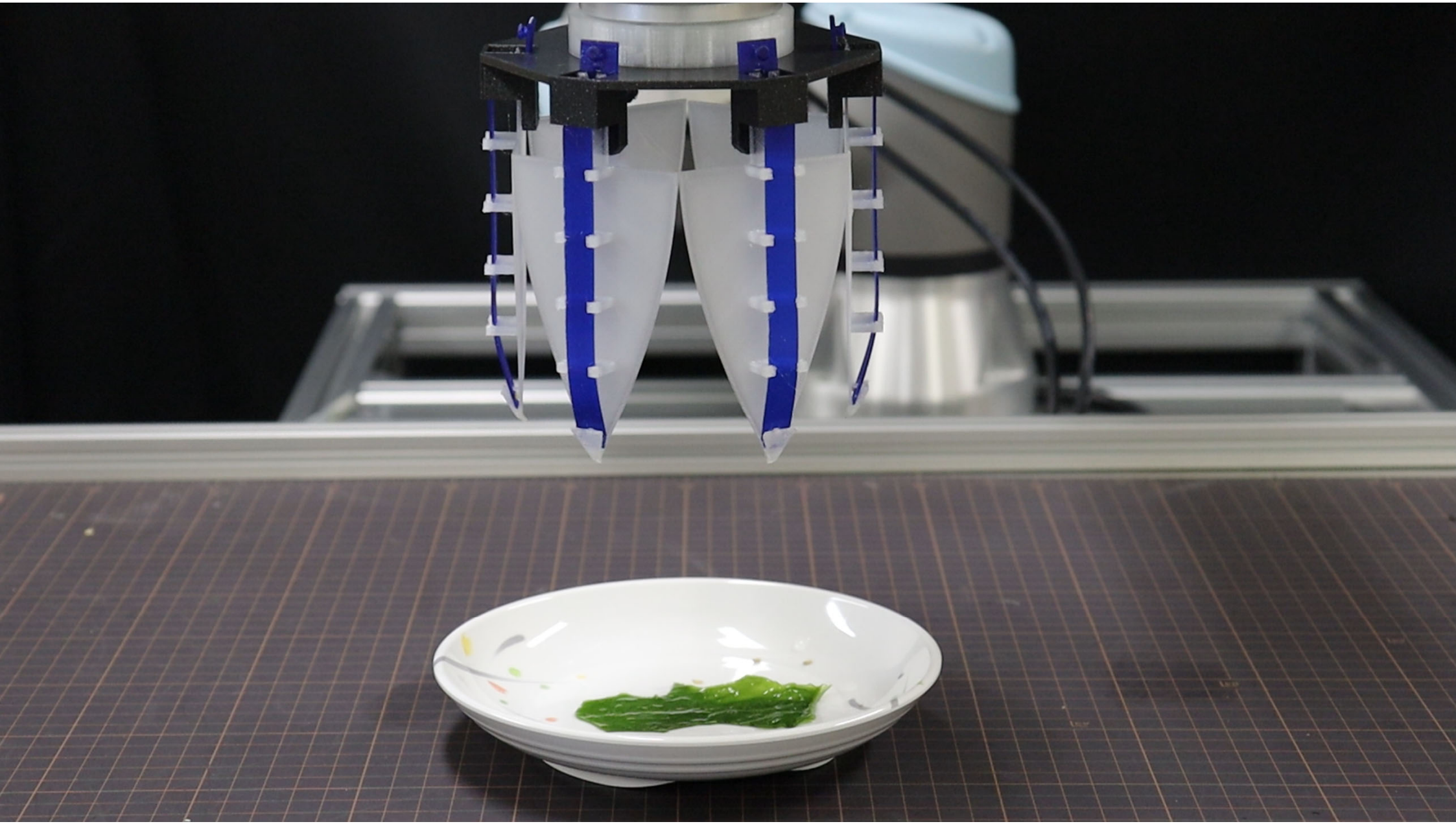


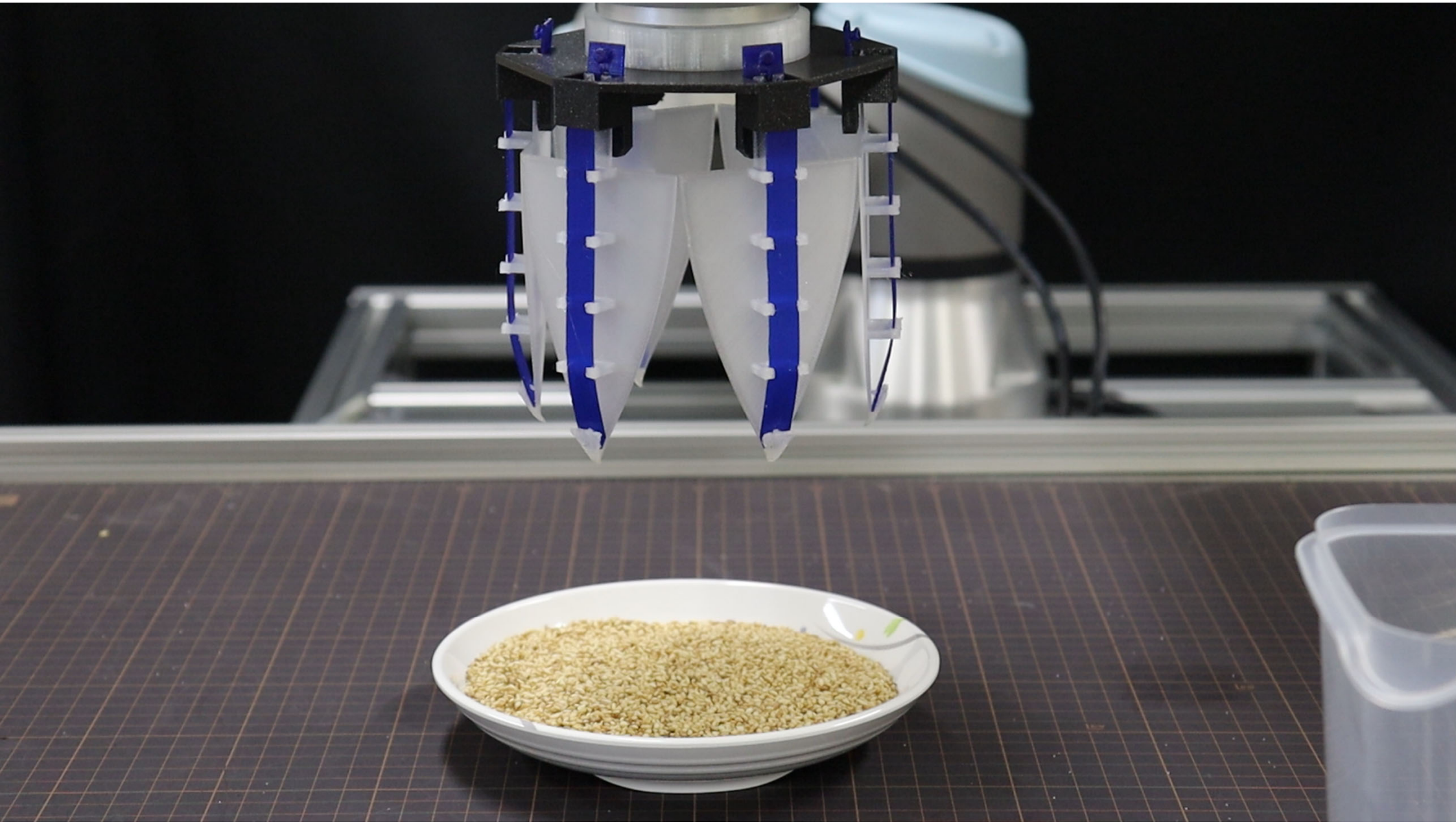
rigid links connected by bolts and nuts



finger consisting of flexible link and plate





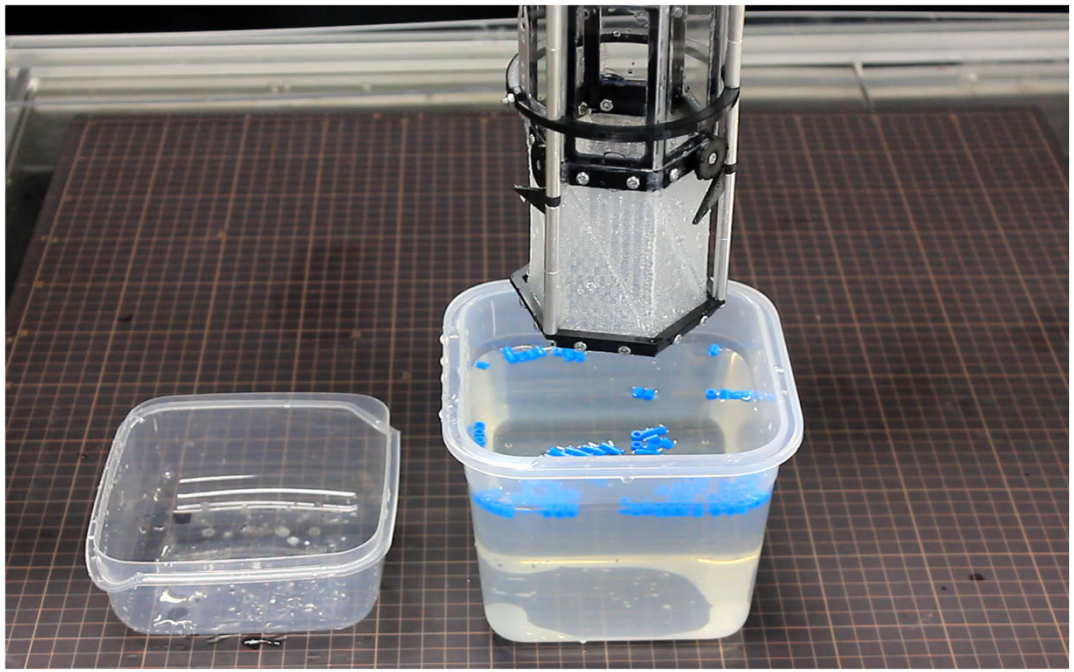


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Origami-membrane Hand

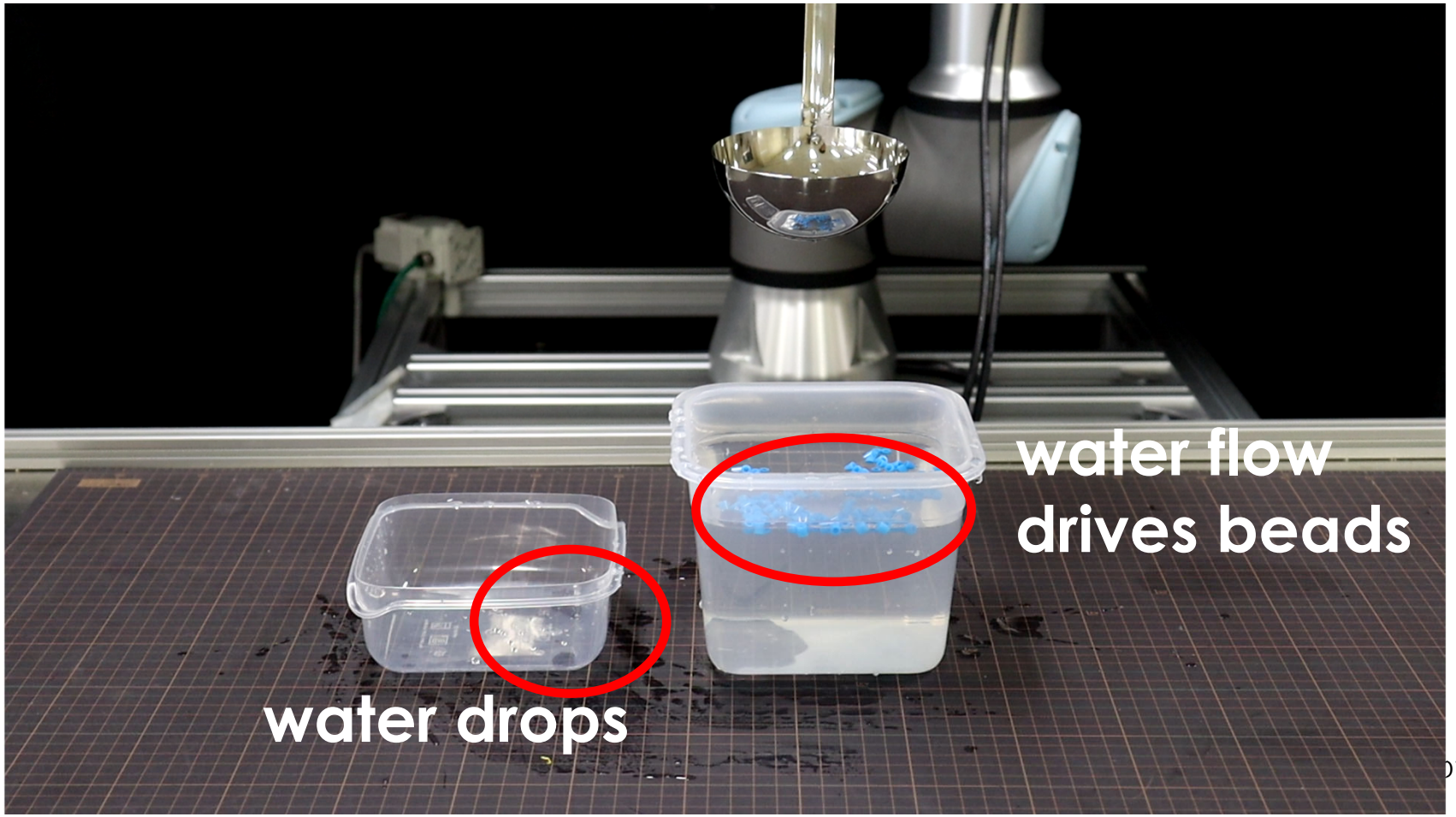
Nate et al., IEEE/SICE SII 2024

Grasping of plankton near bottom ←
Enveloping by origami-membrane



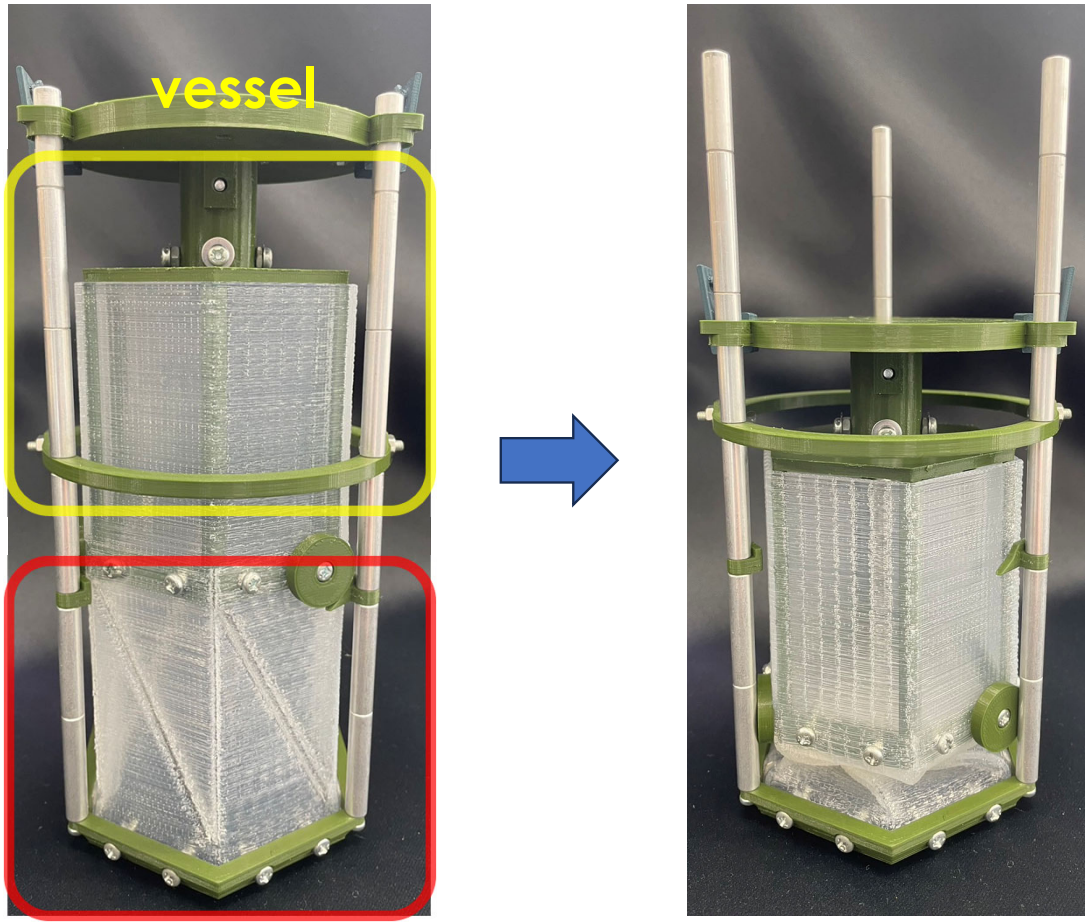
Soft Robotics 2026/10/2

Scooping by ladle



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Origami-membrane Hand

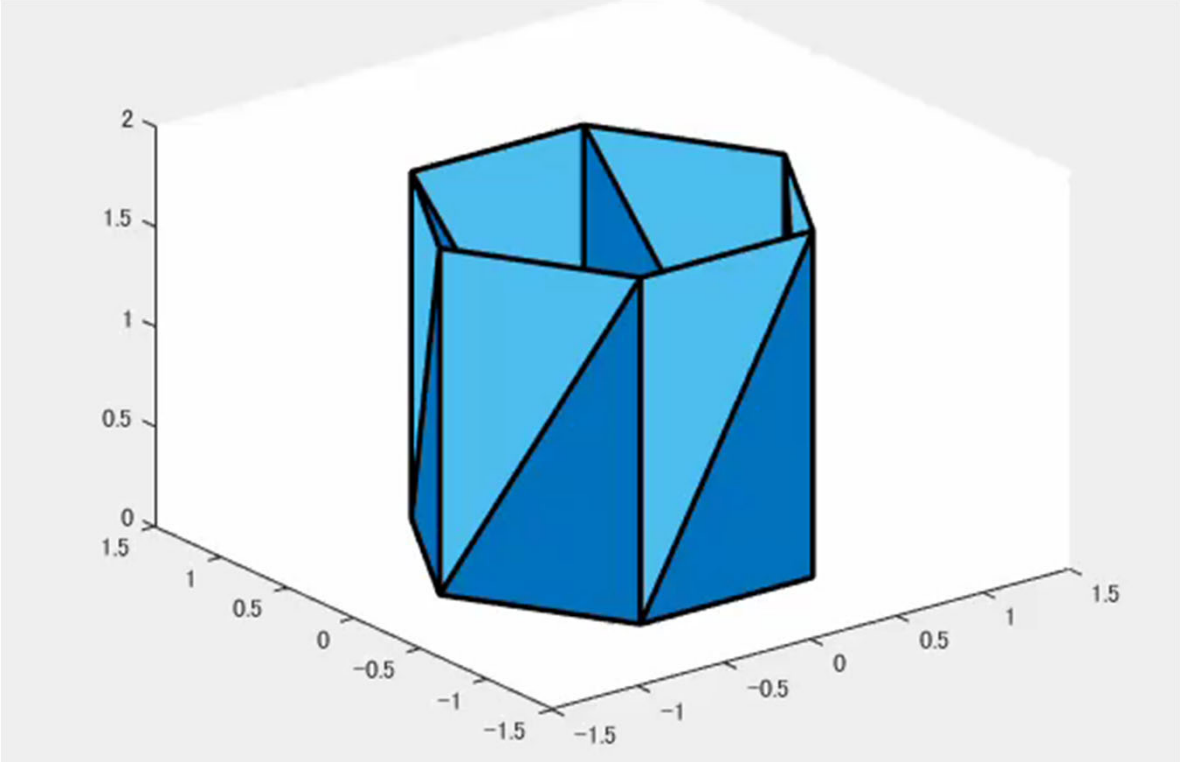


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Origami-membrane

Kresling pattern

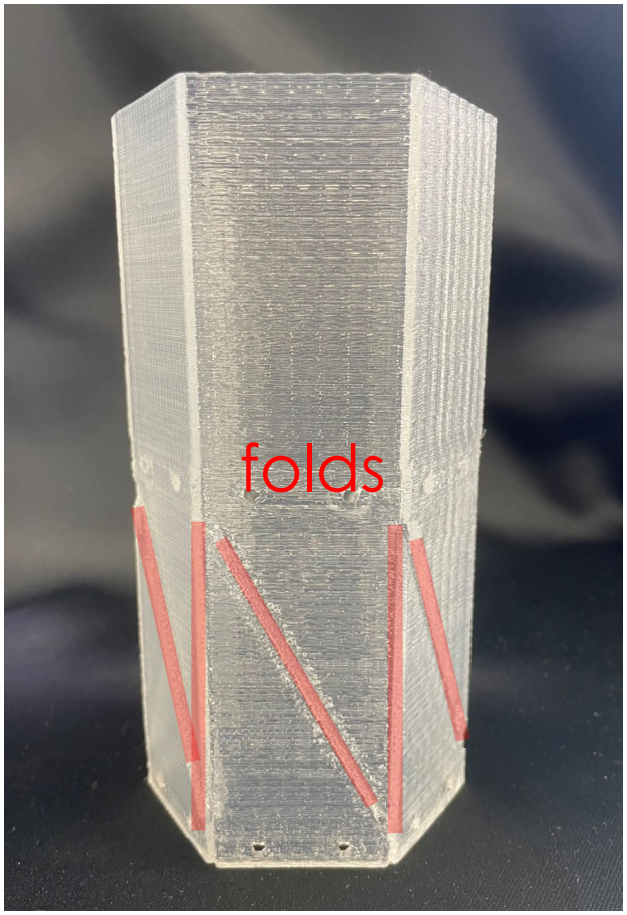
polygonal prism
→ flat shape

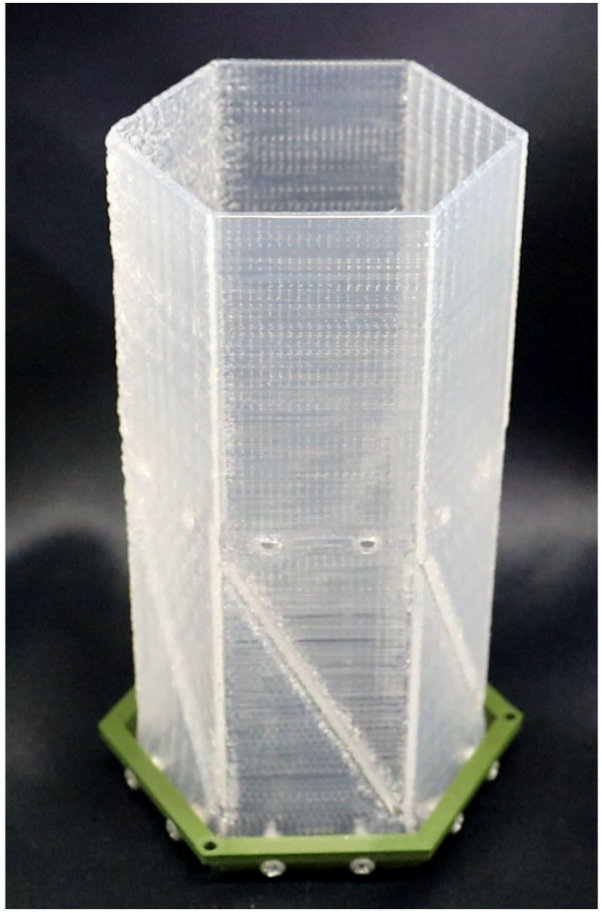


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Fabrication

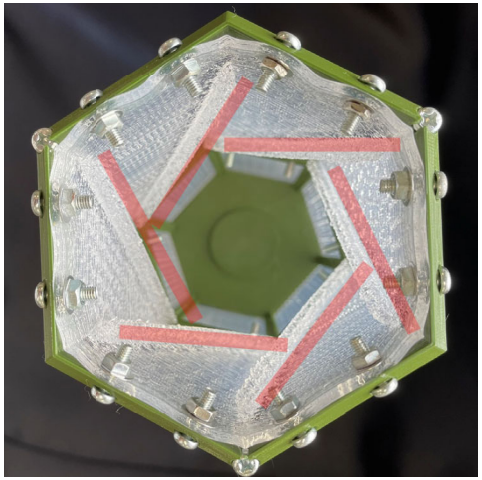
membrane : fabricated
by liquid silicone printer



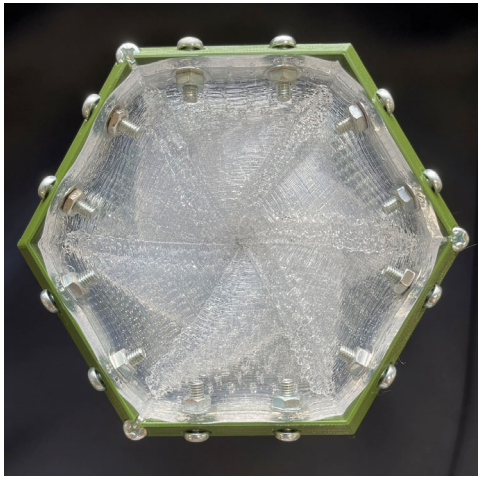


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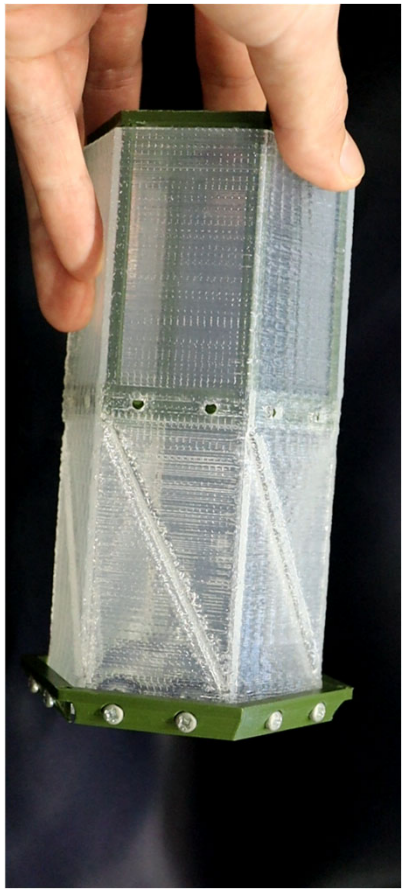
Membrane deformation

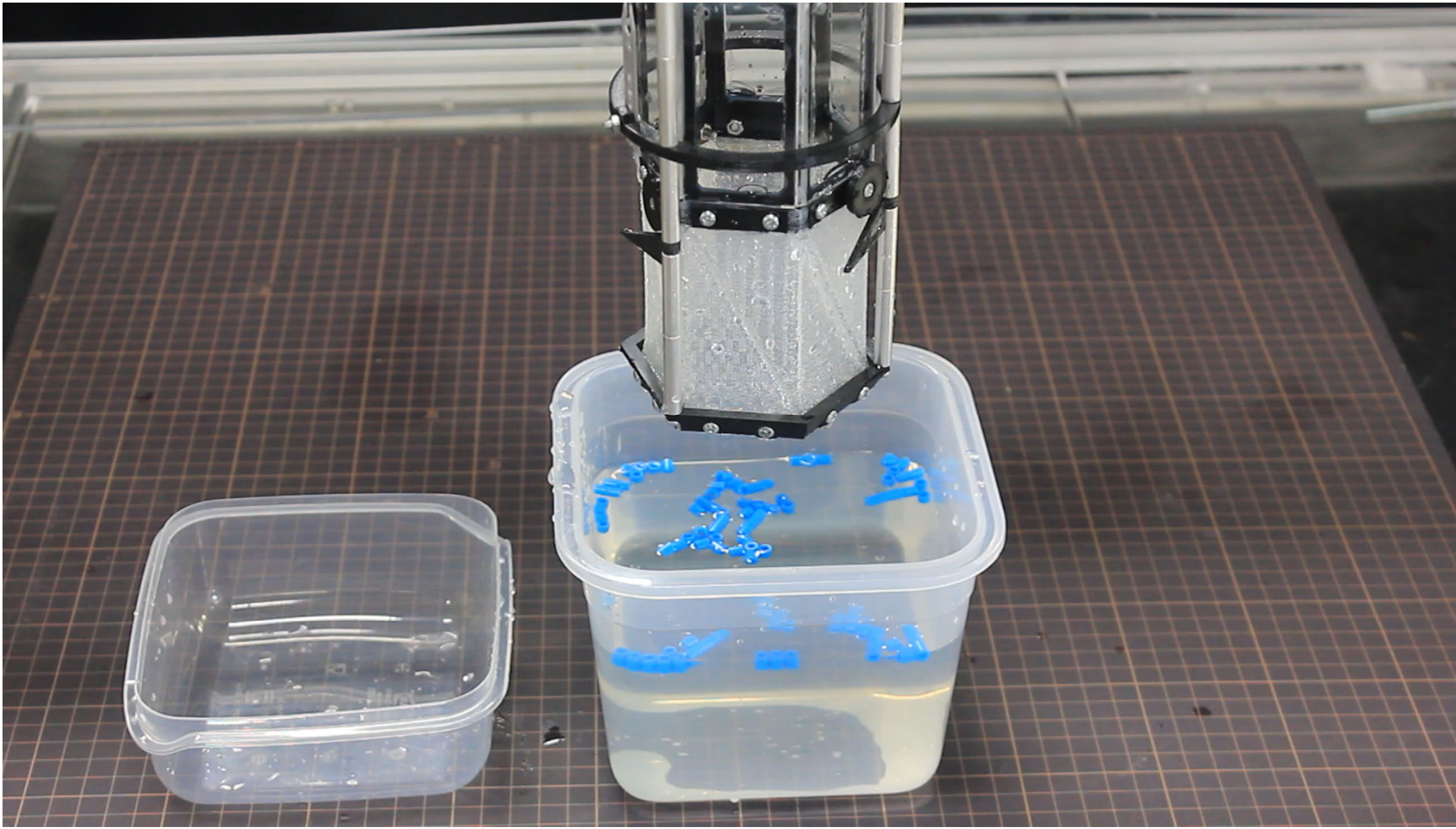


open



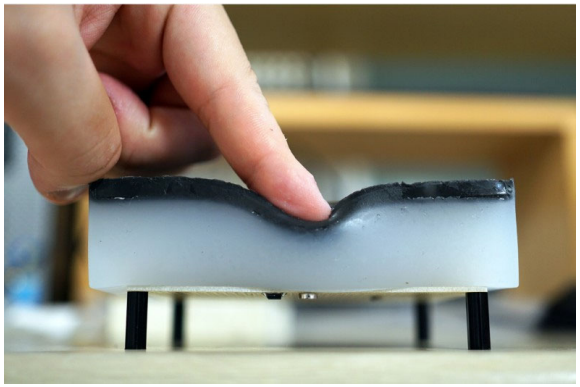
closed



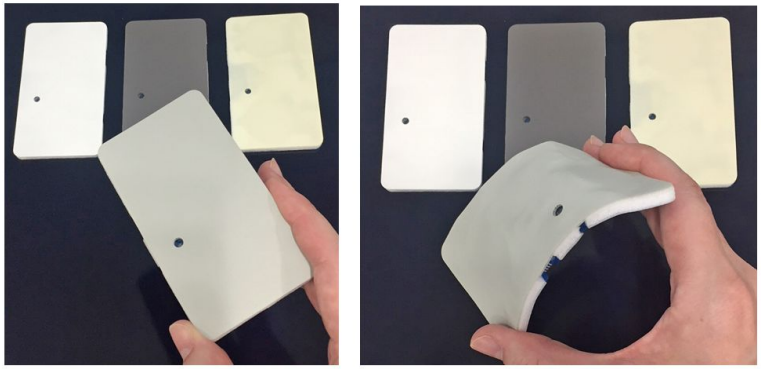


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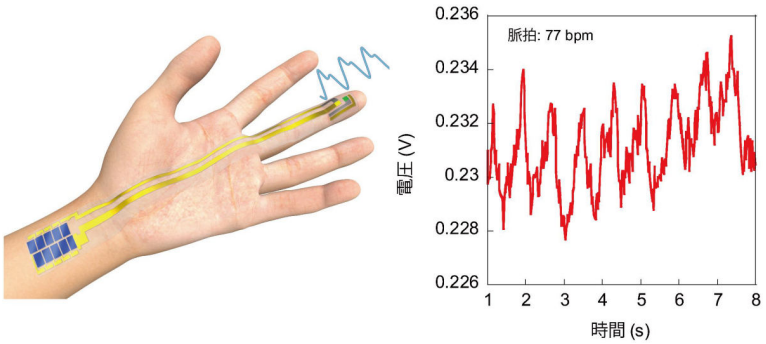
Soft Sensors



http://www.ams.eng.osaka-u.ac.jp/user/ishihara/wp-content/uploads/2016/08/sensor_ver1-e1541744713909.jpg



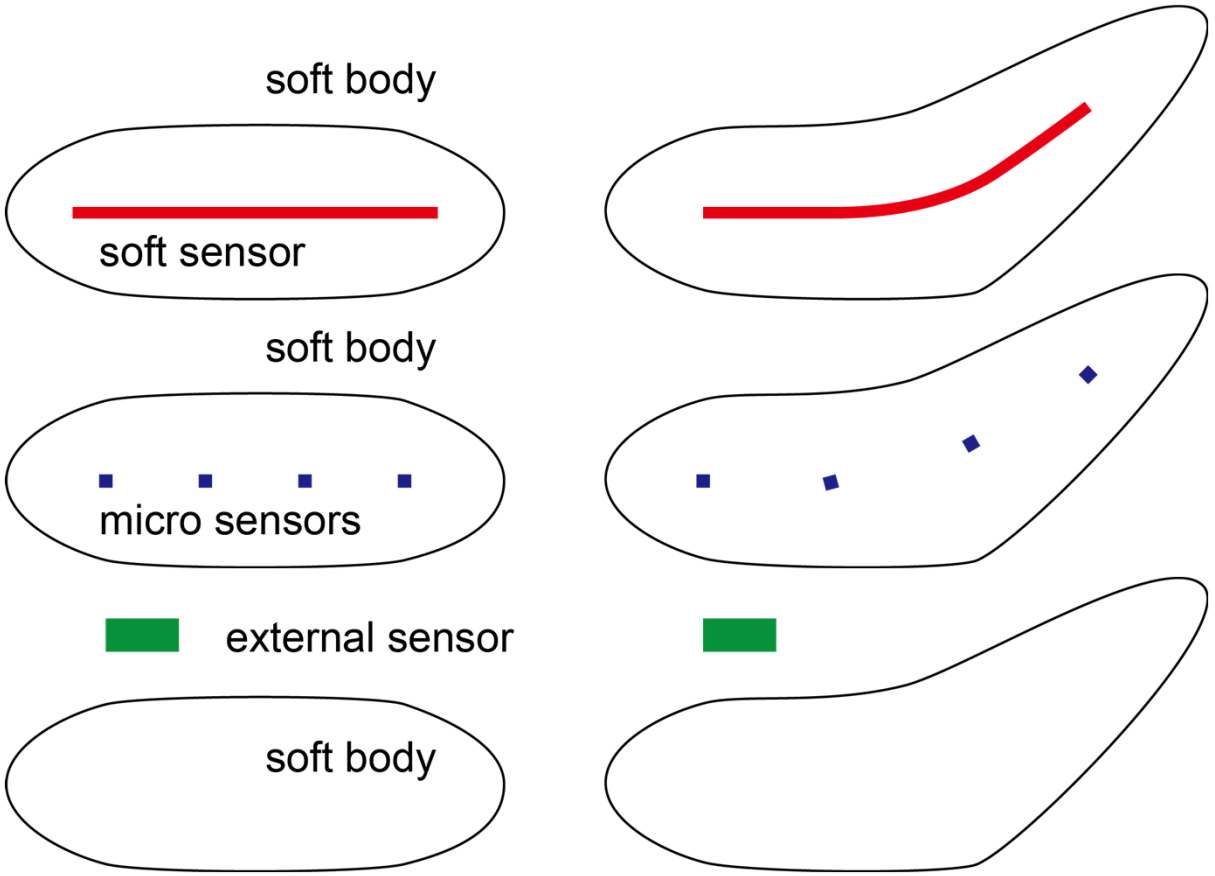
https://www.dic-global.com/news/news_file/file/20190201_%E3%83%93%E3%83%AB%E3%82%BB%E3%83%B3%E3%82%B7%E3%83%B3%E3%82%B0%EF%BC%92.jpg



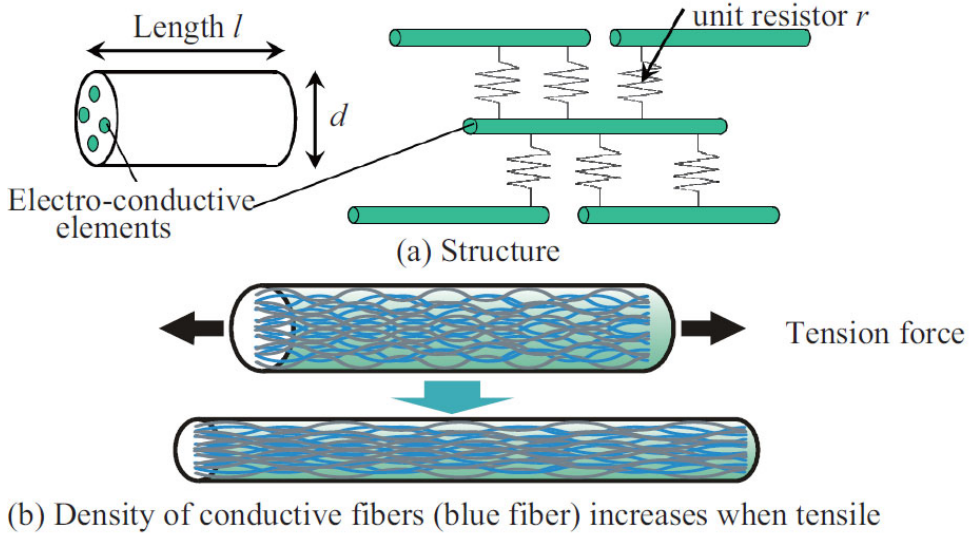
https://news.mynavi.jp/techplus/article/20210422-1876923/images/003.jpg

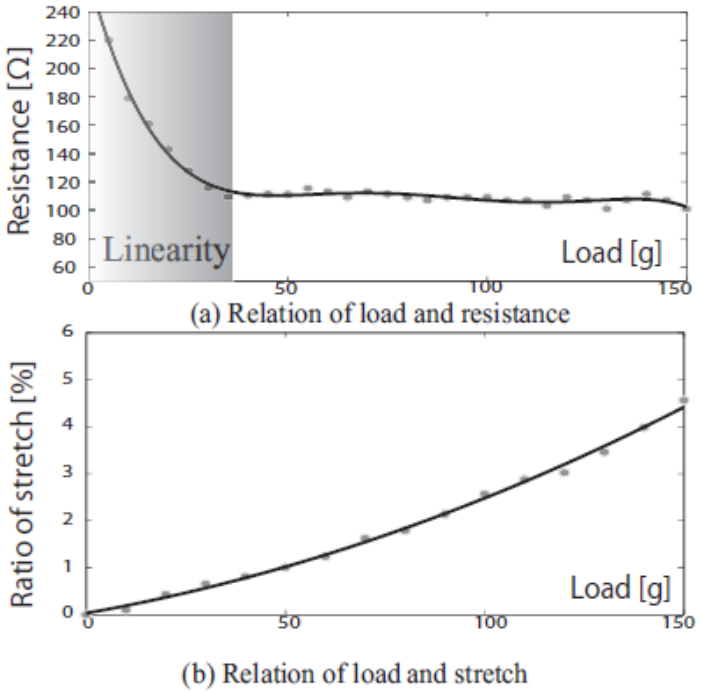
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Sensing for Soft Robots



Fiber Sensor

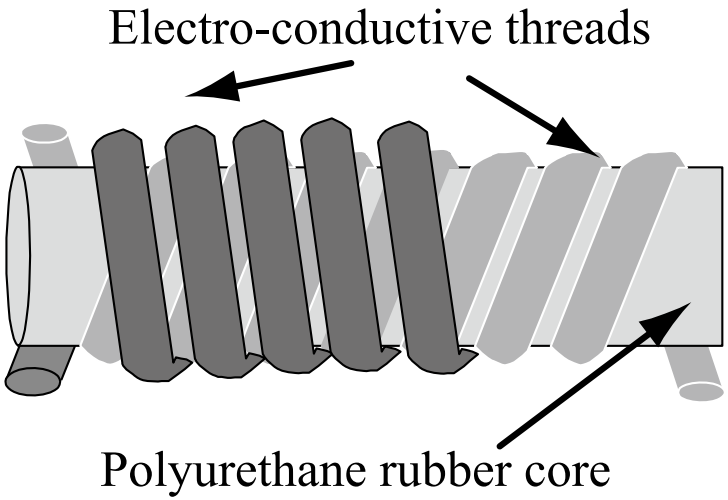


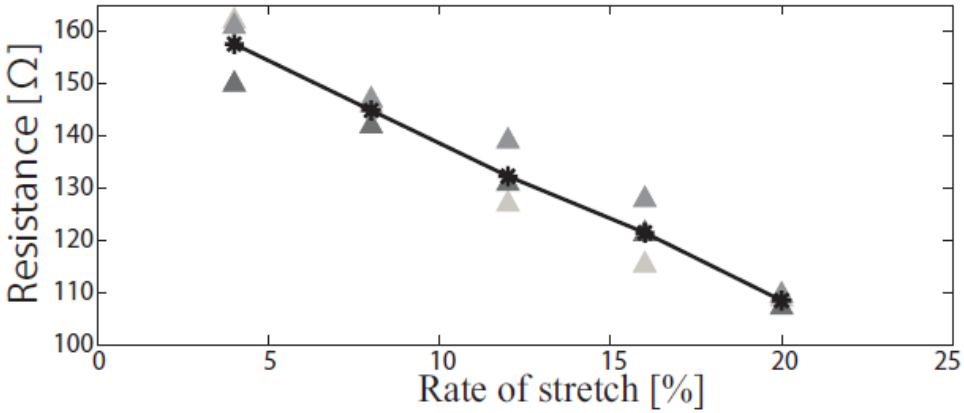


Ho et al., IEEE Sensors J., 13(10), 2013

Sensing range ~ 2%

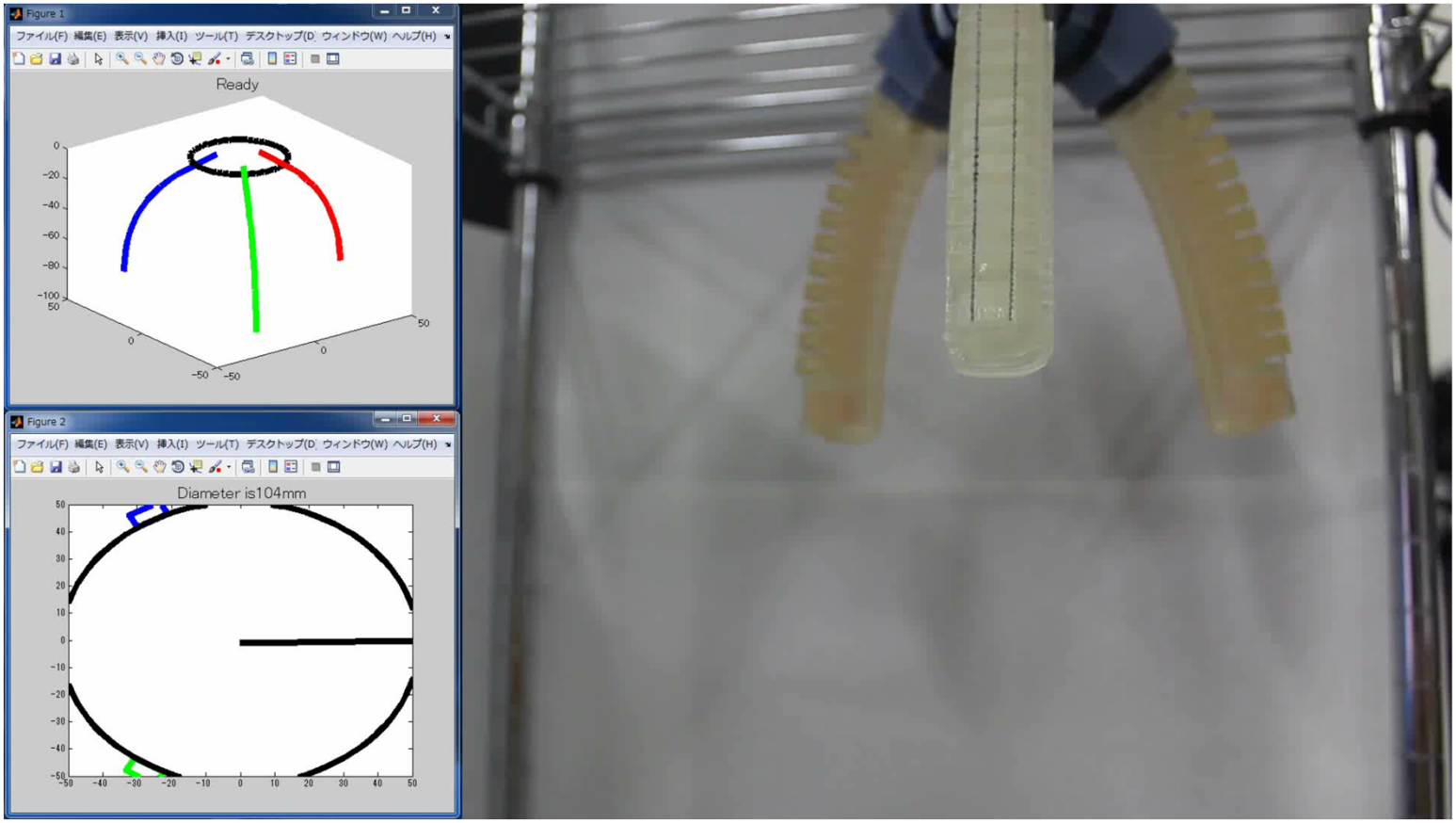
Double-Covering Structure





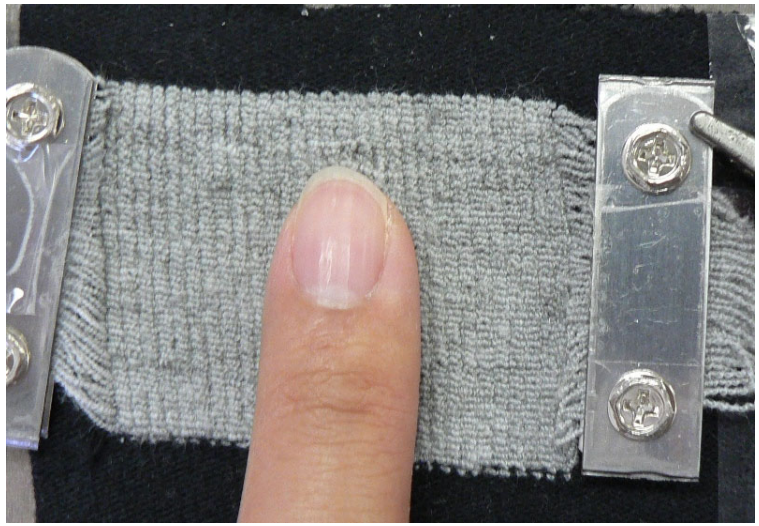
Sensing range ~ 20%

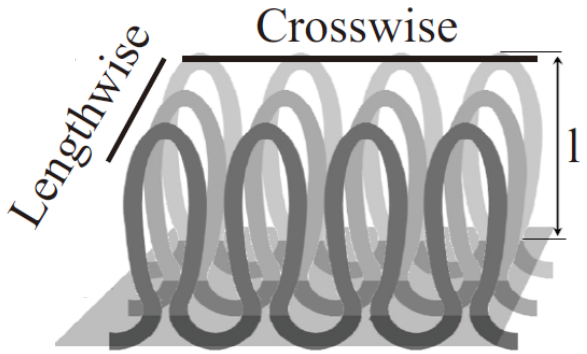
Estimation of finger bending



Matsuno et al., IEEE RCAR 2017

Fabric Sensor

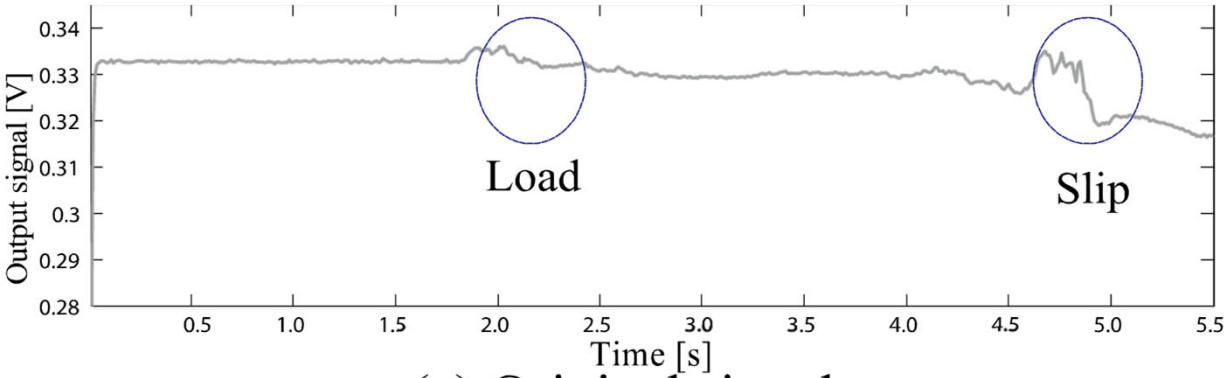




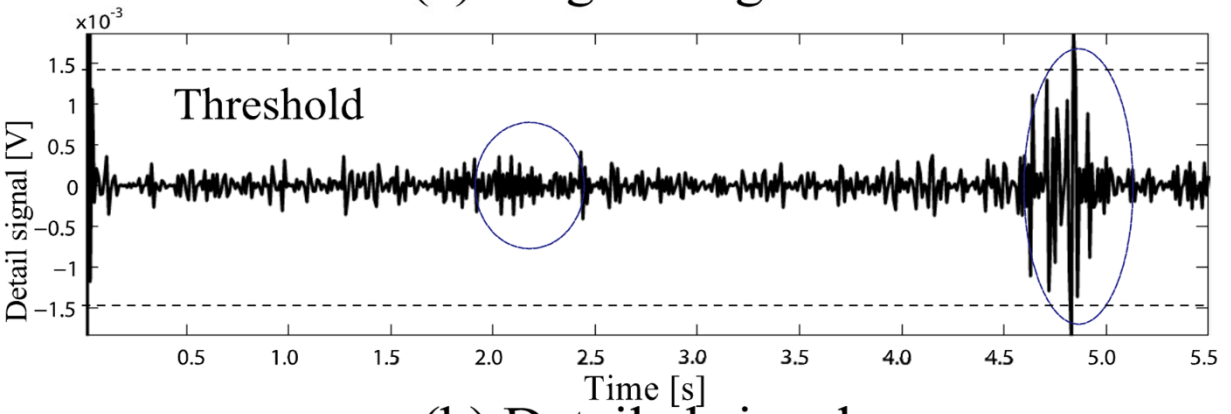
Slip Detection

Wavelet transform Amplitude of high-frequency

Van Ho and Shinichi Hirai
Robotics: Science and Systems VII
pp.129-136, 2012

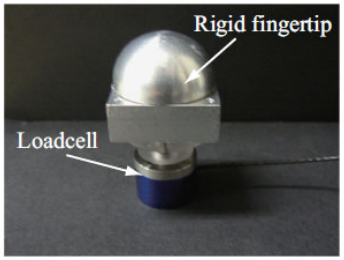


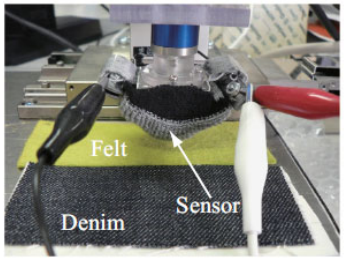
(a) Original signal

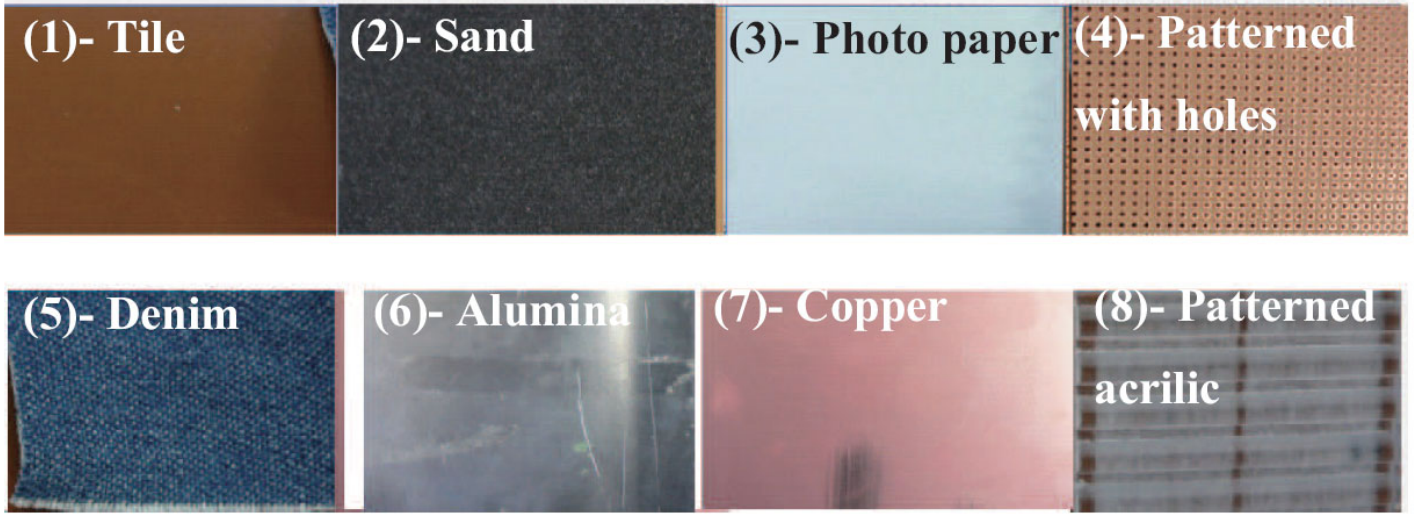


(b) Detailed signal

Discriminating Surface Textures







Ho, Makikawa, and Hirai, IEEE Sensors Journal, 2013

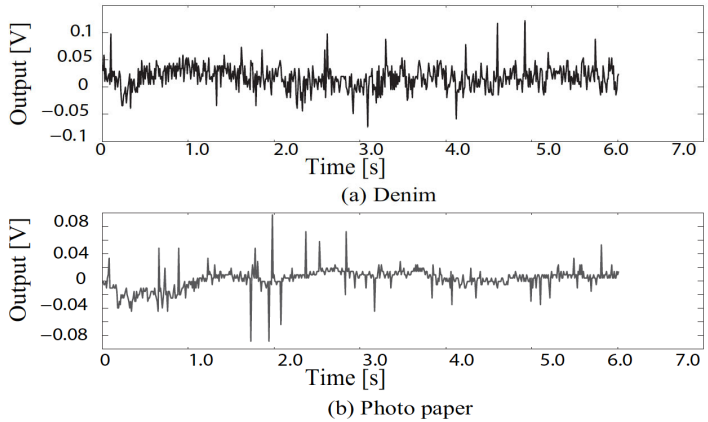
Discriminating Surface Textures



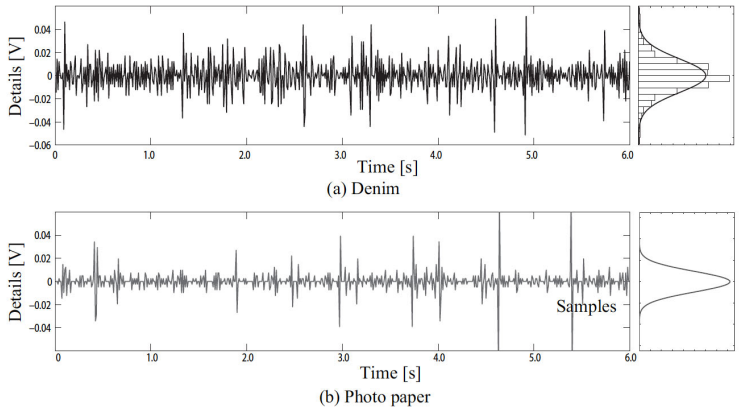
センサ　　離散ウェーブレット変換　　特徴量の計算　　人工ニューラルネットワーク

デニム

写真用紙



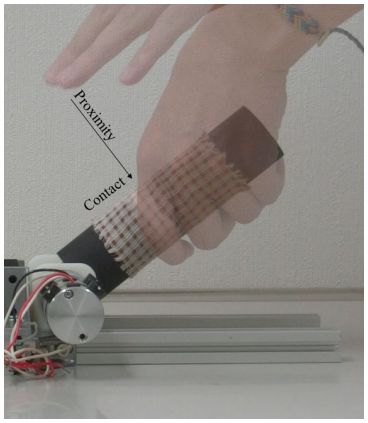
布センサの出力

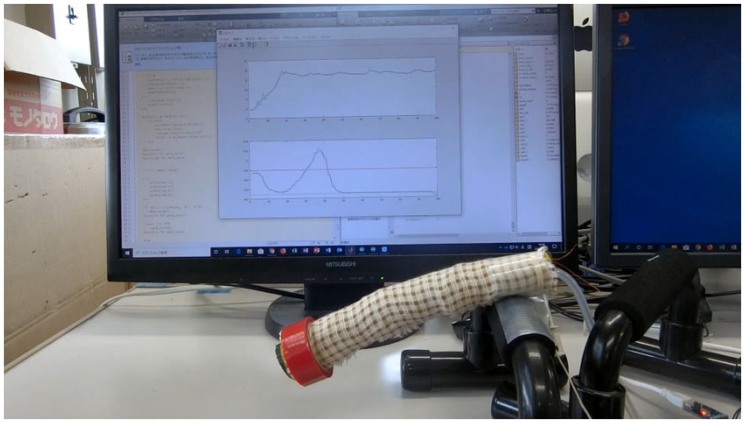


離散ウェーブレット変換の詳細係数

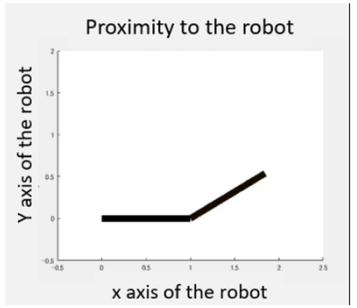
Fabric-based Proximity/Contact Sensor

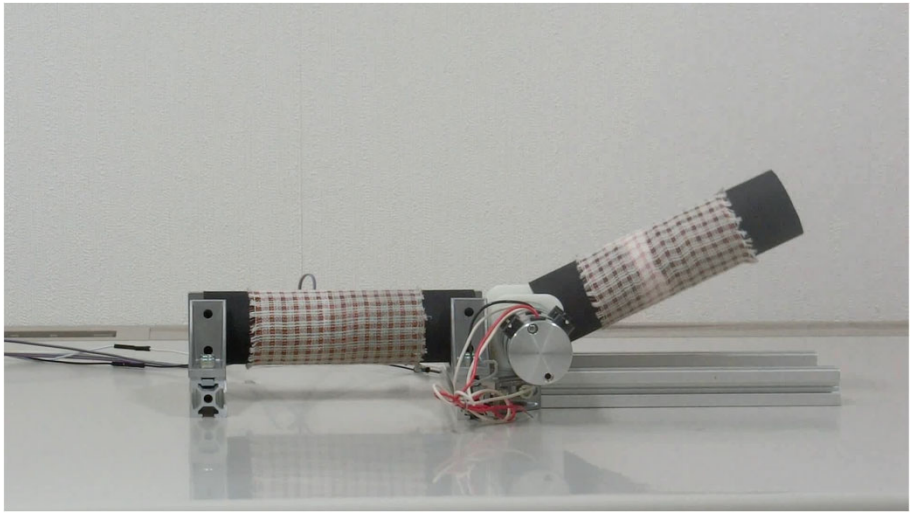
Sensor made of conductive fabric
Can detect approaching/contacting objects





■ → ■:Proximity
■:Contact

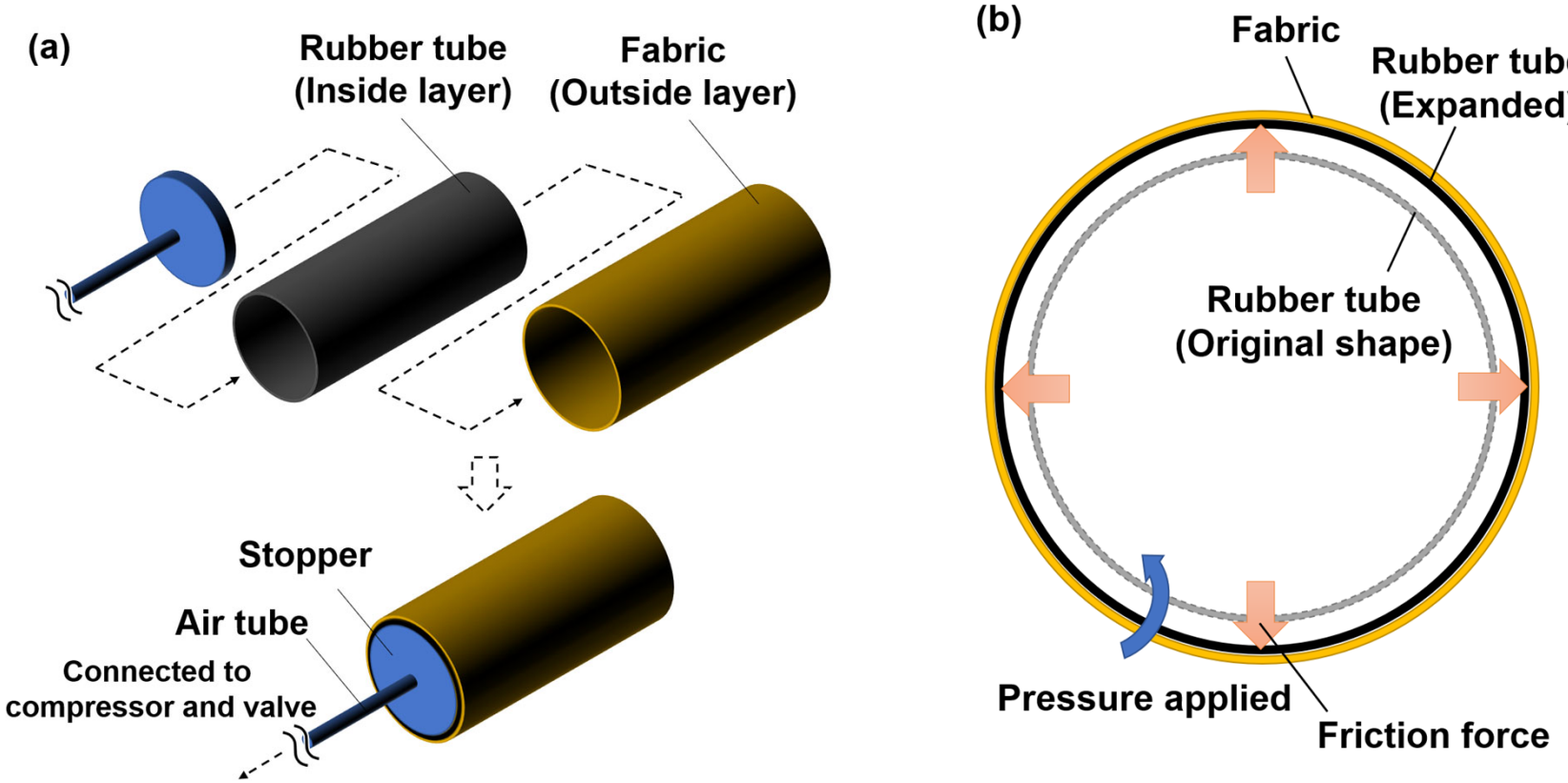




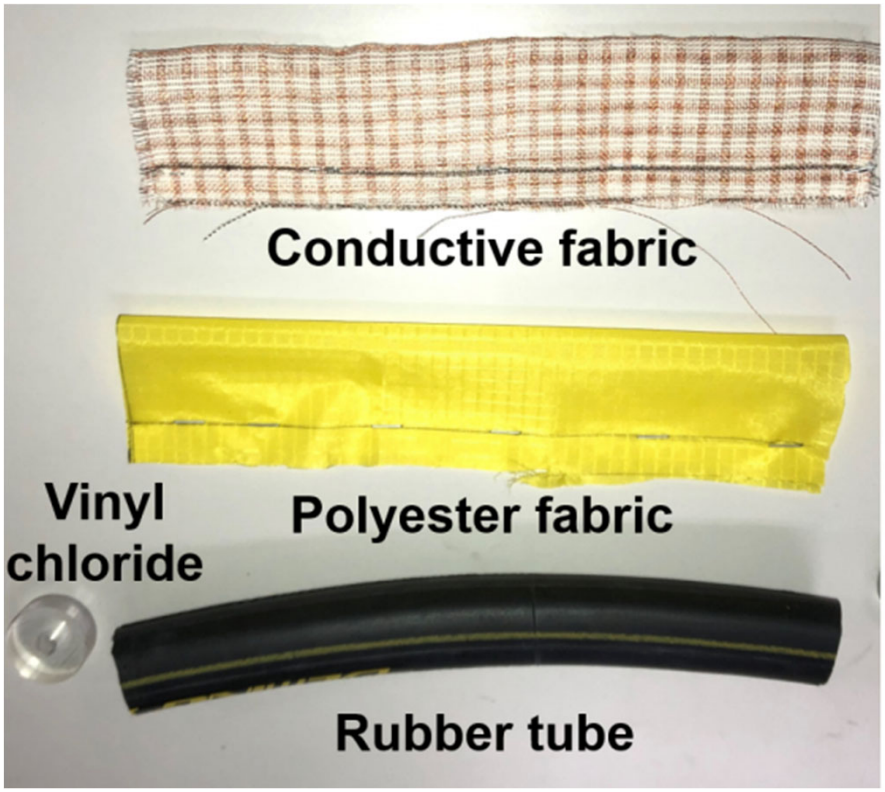
Can cover curved surfaces of rigid/soft robots
Applicable to safety sensors of robots



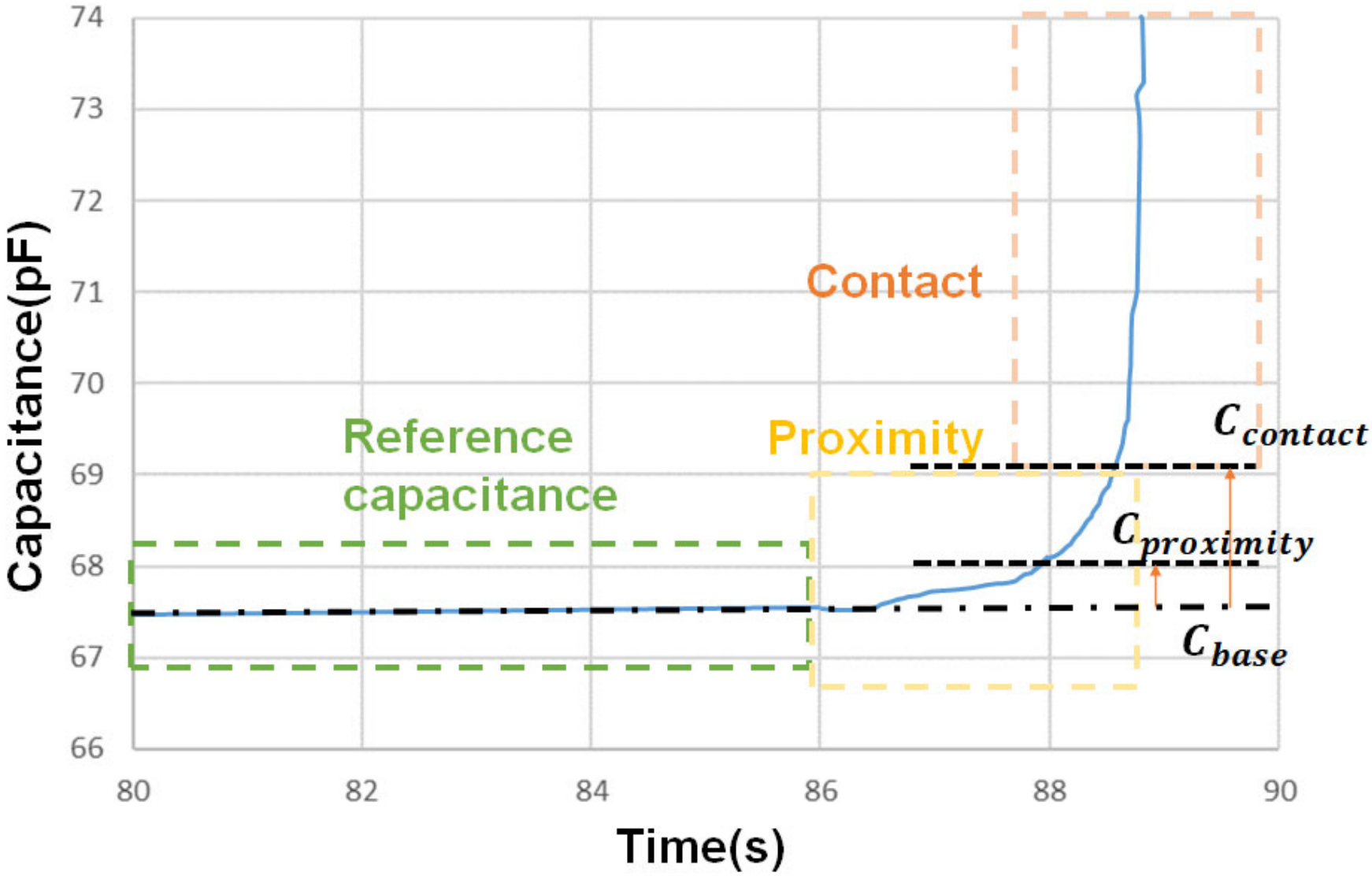
Variable Stiffness Link with Fabric Sensor



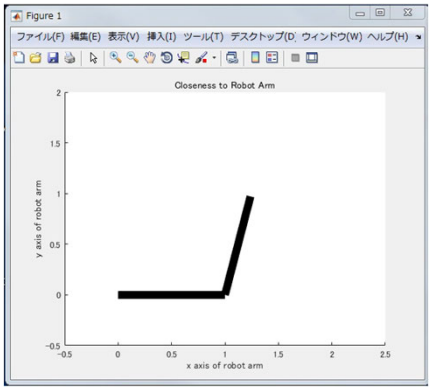
Variable Stiffness Link with Fabric Sensor





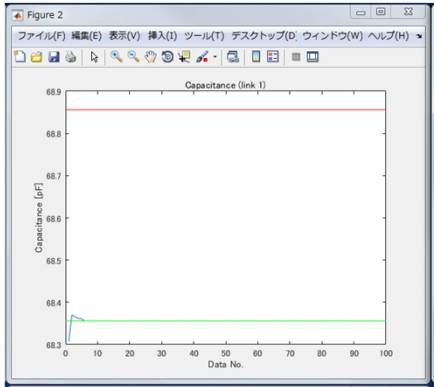

74
73
72
71
70
69
68
67
66
Capacitance(pF)
80
82
84
86
88
90
Time(s)
Contact
Proximity
Reference
capacitance
$C_{contact}$
$C_{proximity}$
C_{base}

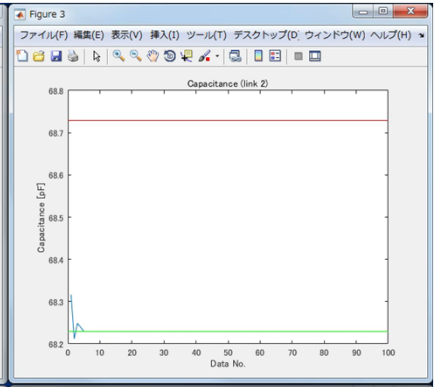
Matsuno et al., IEEE RAL, 4(2), 2212-2219, 2019

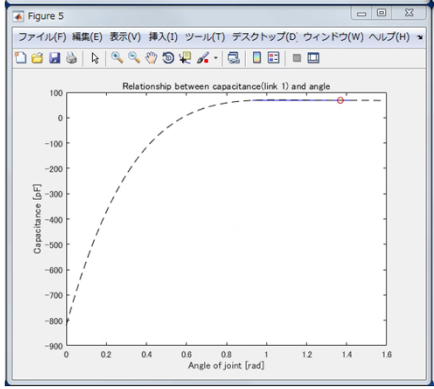


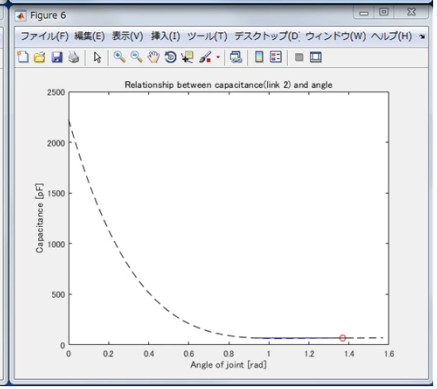
:Proximity
:Contact

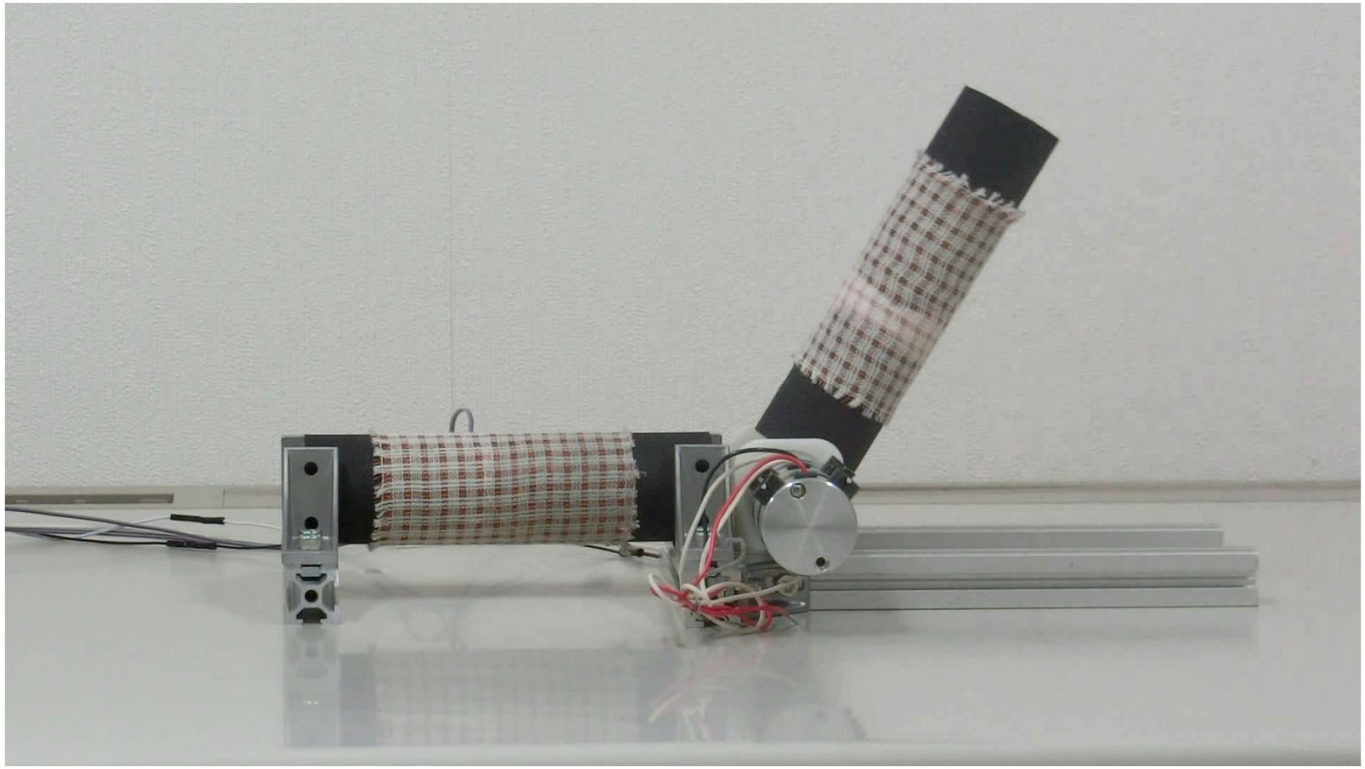
:Measured
:Reference





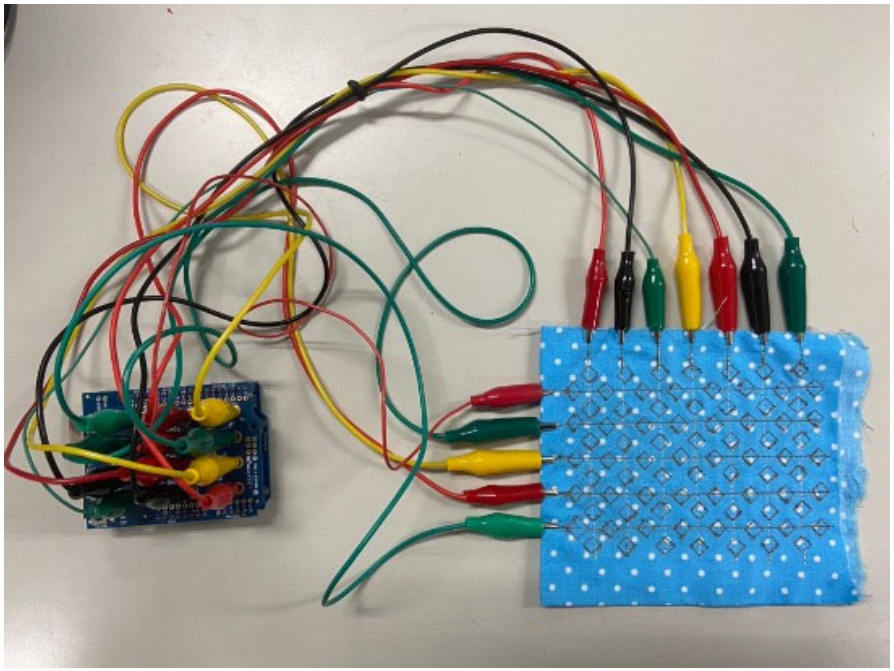


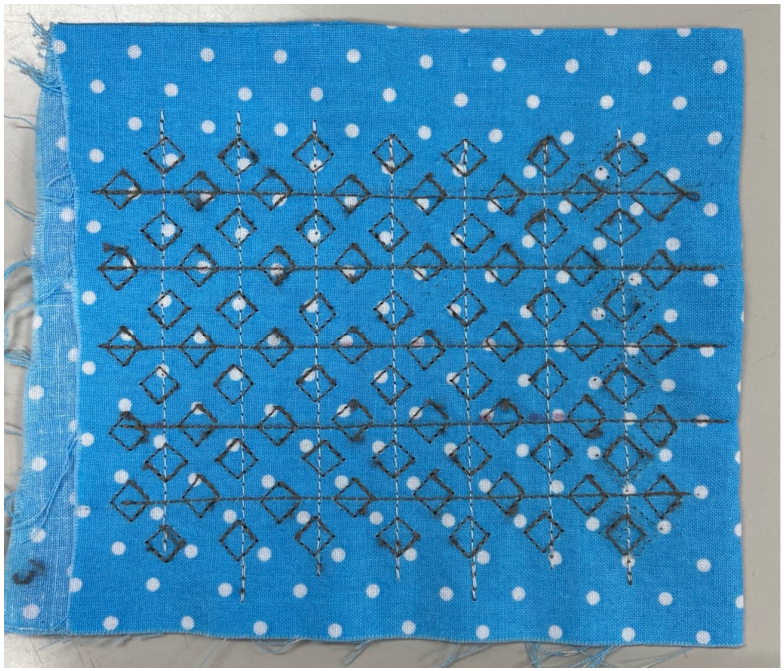




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Fabric Touch Sensor

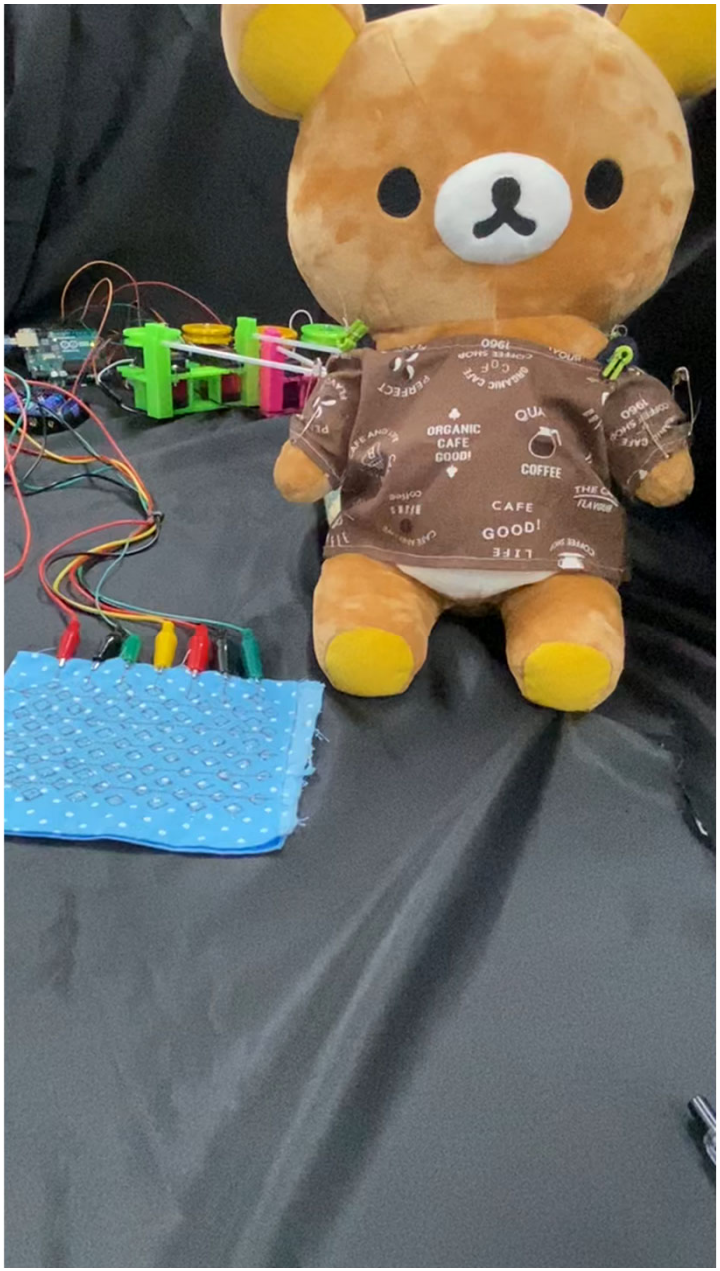
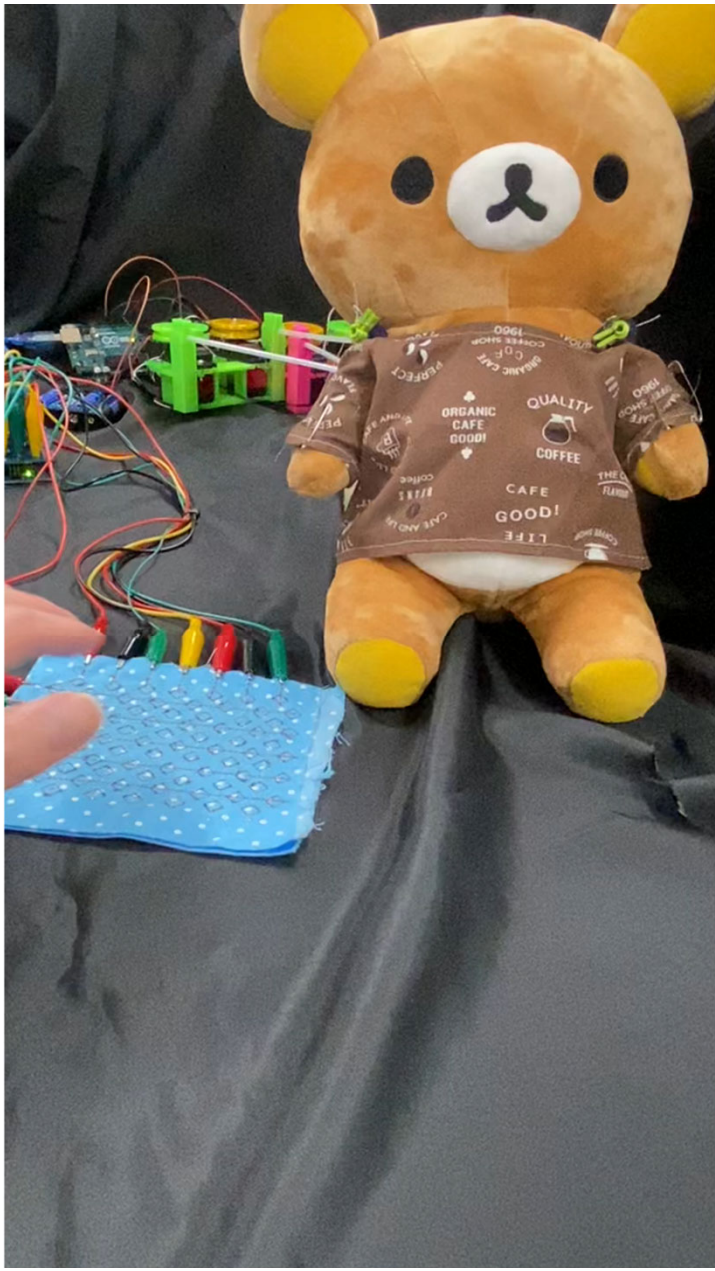






Shinichi Hirai and Takahiro Matsuno, Finger Stroke Detection by Fabric Touch Panel with its Application to Stuffed Animal Robot, SICE 2024

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Softness is Opportunities

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More Details

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