



# ソフトロボティクス

平井 慎一

立命館大学ロボティクス学科

<http://www.ritsumeai.ac.jp/~hirai/>

# ソフトロボティクス Soft Robotics

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ロボットシステムがもつ物理的柔軟性の活用に関する新しい研究分野

生体システムのもつ「やわらかさ」に注目し、生体システムの価値観に基づいた自律する人工物の創造を目指す

柔らかい材料を積極的に用いて新しい機能を発現するロボットに関する研究

# ソフトロボティクス Soft Robotics



## SIG Soft Robotics

Special Interest Group on Soft Robotics

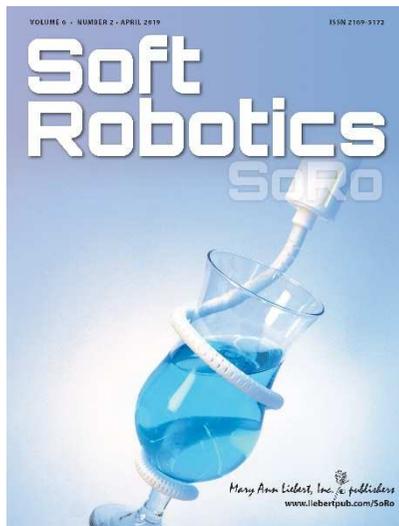


# Soft Robotics

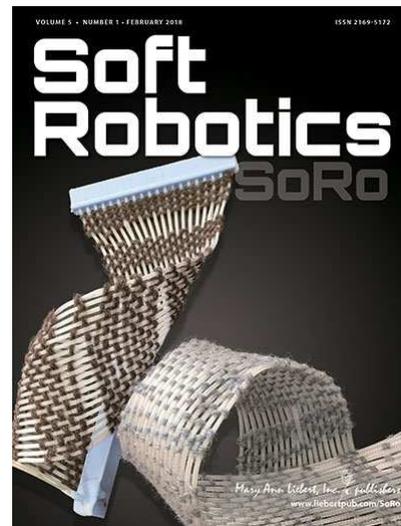
Impact Factor 5.057 (2017)

Mary Ann Liebert, Inc.

医学・薬学・生物学系の出版社



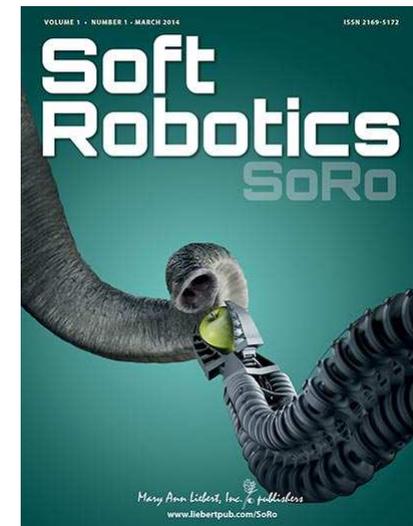
Vol. 6, No.1  
Feb. 2019



Vol. 5, No.1  
Feb. 2018



Vol. 3, No.1  
March 2016



Vol. 1, No.1  
March 2014

# IEEE Int. Conf. on Soft Robotics

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2018年 第1回 イタリア・リヴォルノ

特殊講義 I 2019/4/27

# Soft Robotics Lab

指導 平井 慎一

ロボティクス学科 教授

設立 1996年4月

[びわこ・くさつキャンパス\(BKC\) アクセス](#)

[びわこ・くさつキャンパス\(BKC\) マップ](#)

[予定表](#)

ソフトロボティクス研究室では、柔らかい材料を積極的に用いて新しい機能を発現するロボットに関する研究を幅広く進めています。

近年のメインテーマ (詳細は[こちら](#))



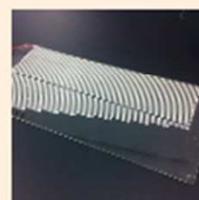
[プリンタブルハンド](#)



[柔軟指先センサ](#)



[飛行ロボット](#)



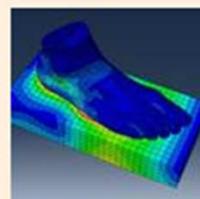
[面状曲げセンサ](#)



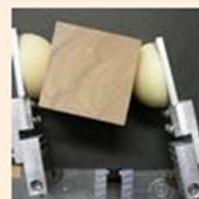
[バインディングハンド](#)



[マイクロ流体弁](#)

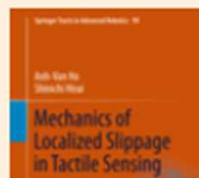


[足の力学モデリング](#)



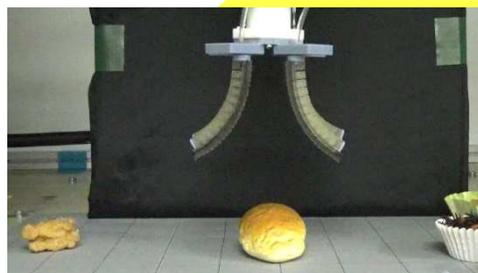
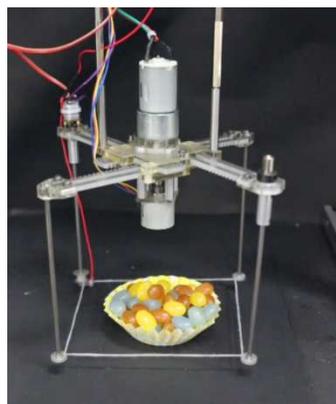
[柔軟指操作](#)

書籍

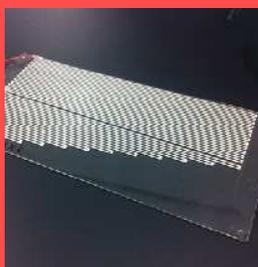
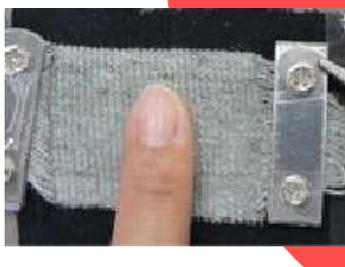
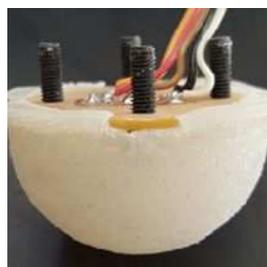
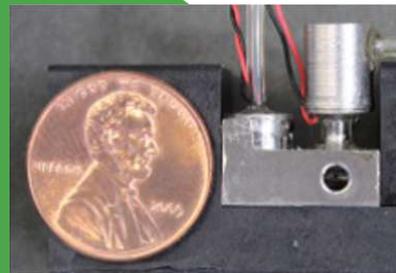


# ソフトロボティクス研究室

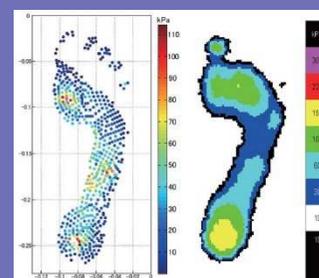
## 柔軟物ハンドリング



## 空気圧駆動ロボット



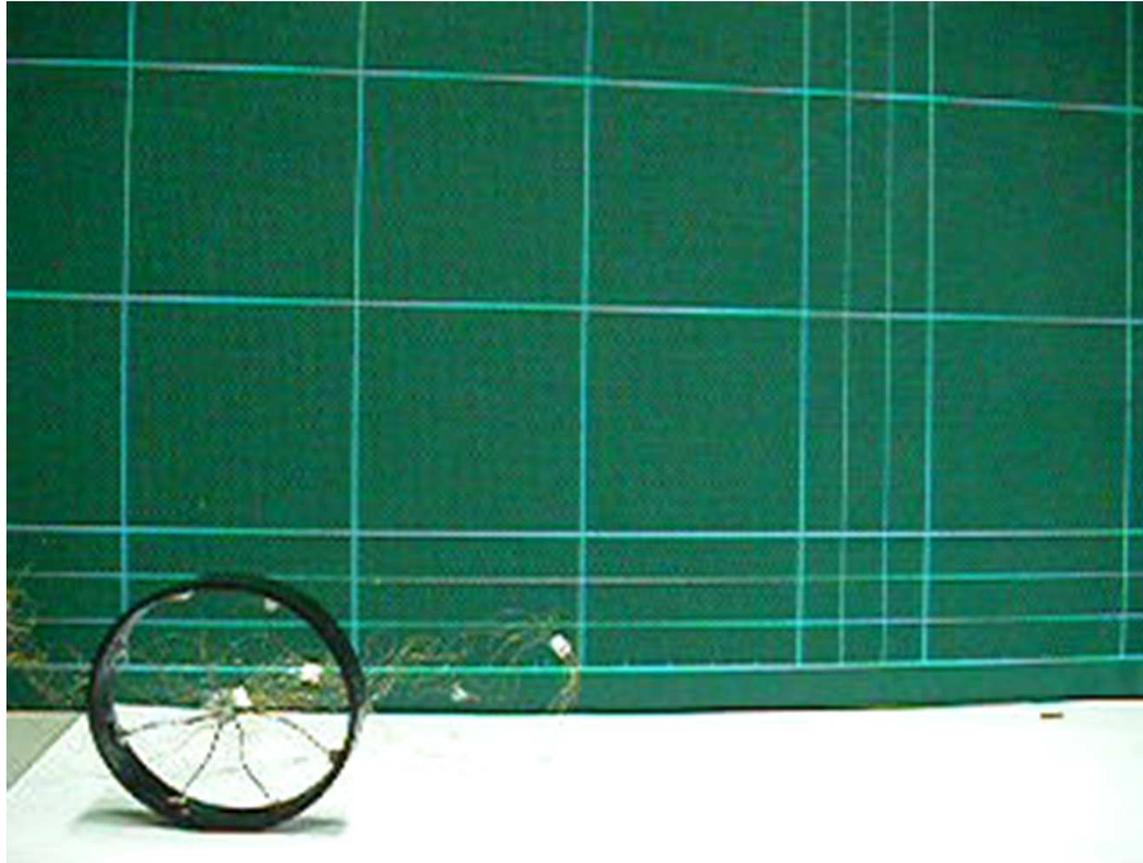
## 触知覚センシング



## 人体モデリング

# 円形ソフトロボット

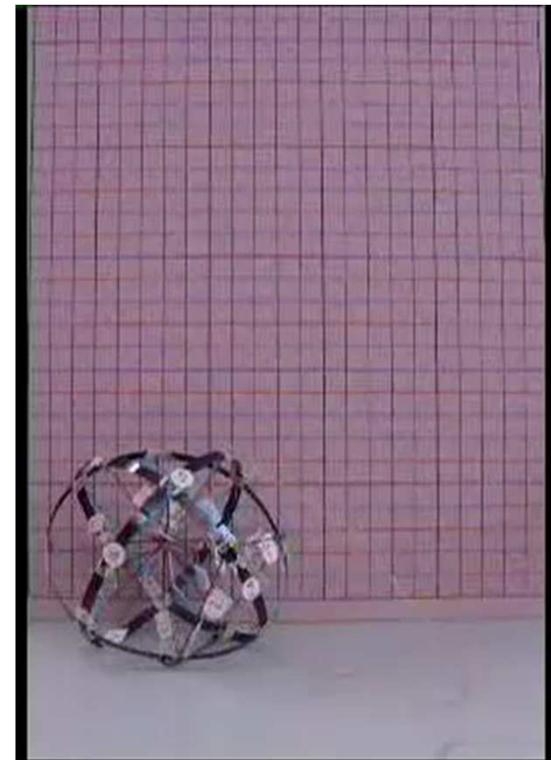
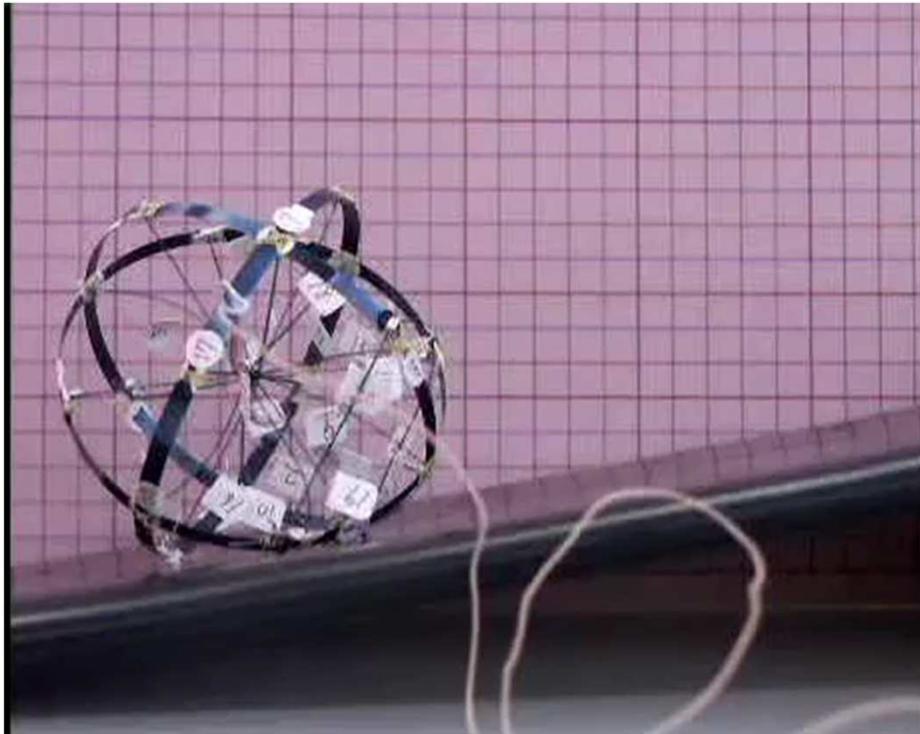
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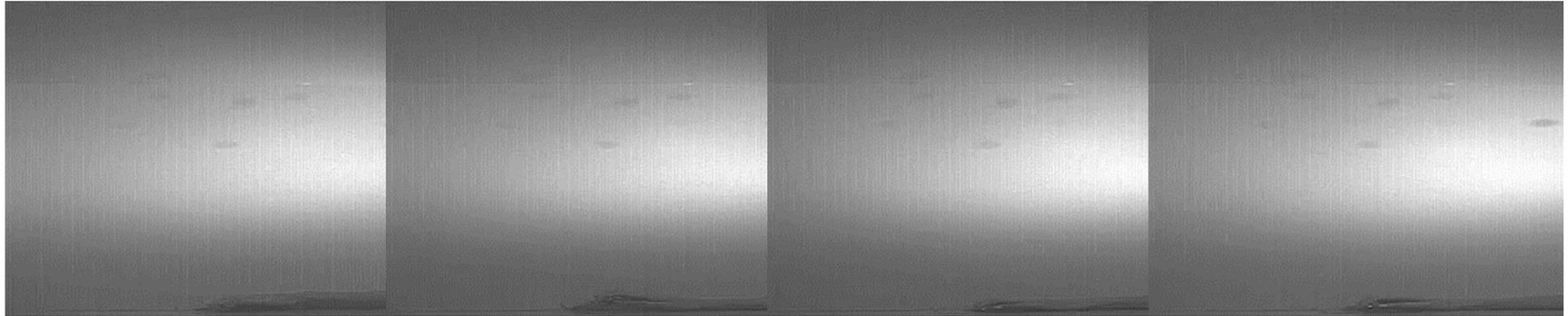
Sugiyama and Hirai, Crawling and Jumping by a Deformable Robot,  
IJRR, 25-5/6, 603-620, 2006

# 球形ソフトロボット

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# 変形による跳躍

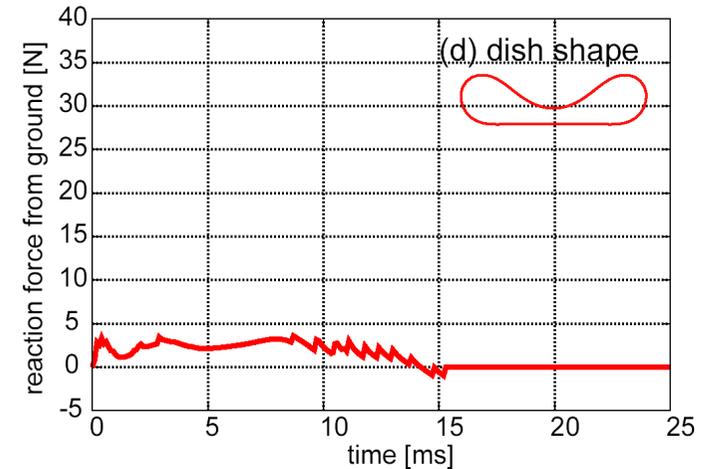
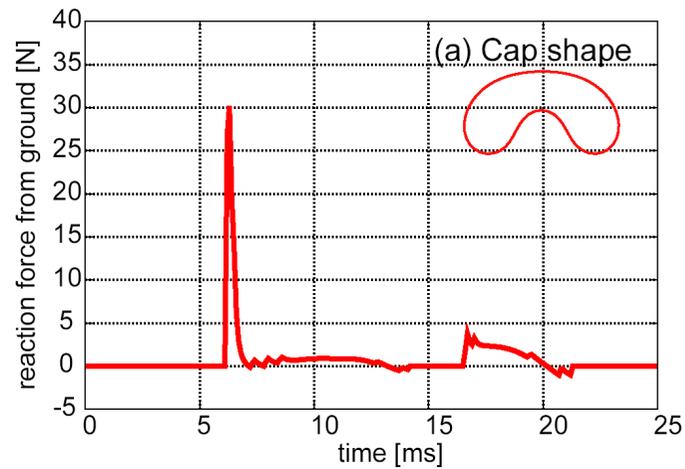


Cap 

Cup 

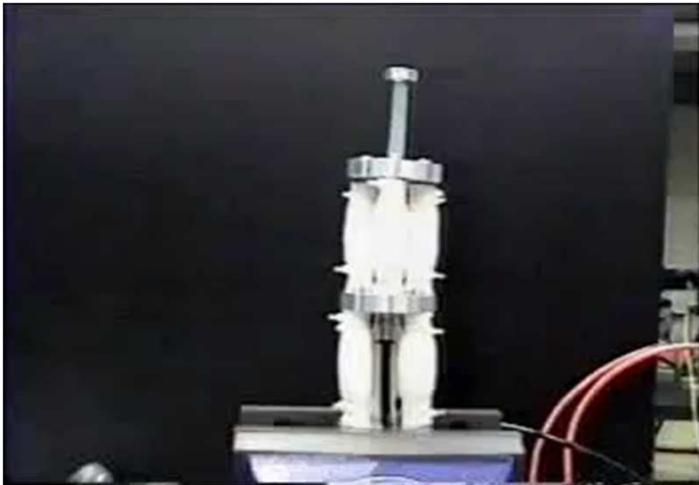
Peanut 

Dish 



# ソフトアクチュエータ

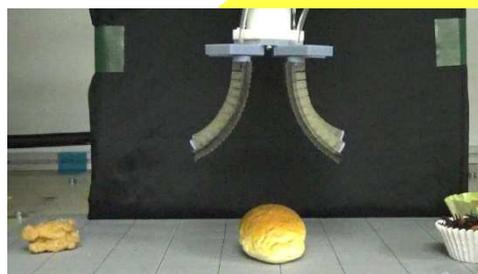
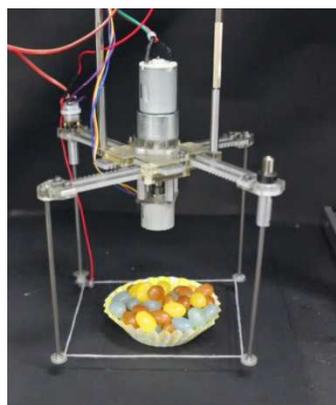
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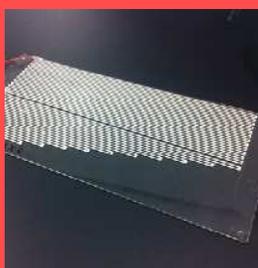
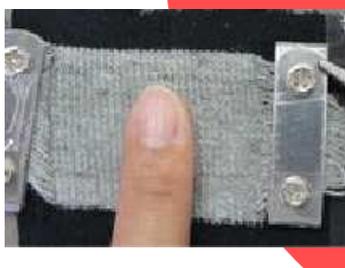
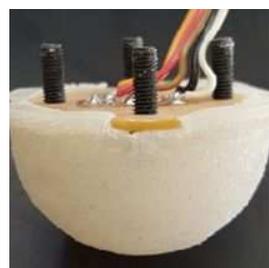
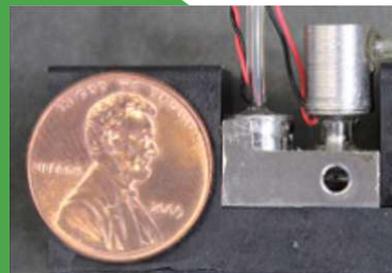
Hirai *et al.*, Prototyping Pneumatic Group Actuators  
Composed of Multiple Single-motion Elastic Tubes,  
IEEE ICRA, 2001

# ソフトロボティクス研究室

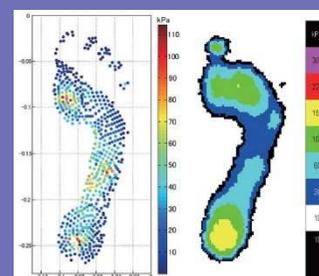
## 柔軟物ハンドリング



## 空気圧駆動ロボット



## 触知覚センシング



## 人体モデリング

# ソフトグリッパー

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# ソフトグリッパー

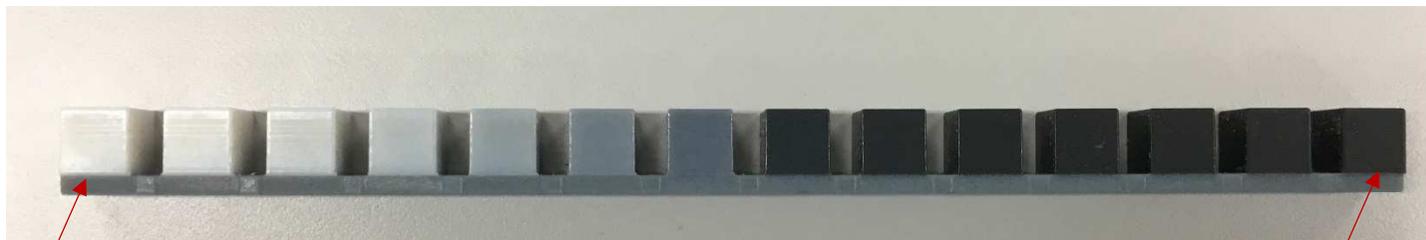


# 三次元プリンタ



Objet260 Connex (Stratasys)

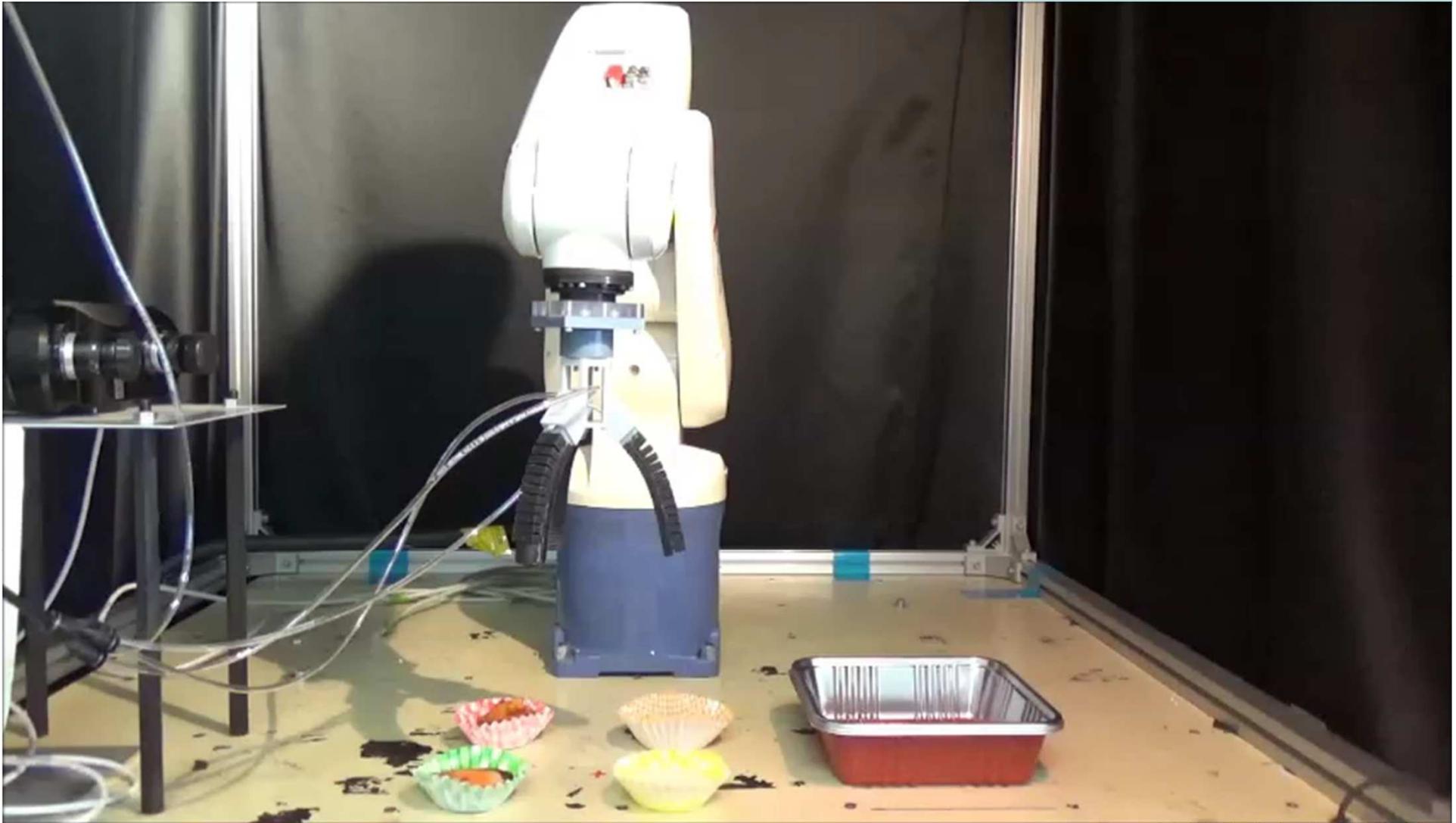
Item	Connex260
Work space	X255mm x Y252mm x Z200mm
Resolution	600dpi x 600dpi x 1600dpi
Layer thickness	30 $\mu$ m
Input file	STL / SLC format
Material	Photopolymer
Multi-material	14 kinds material simultaneously



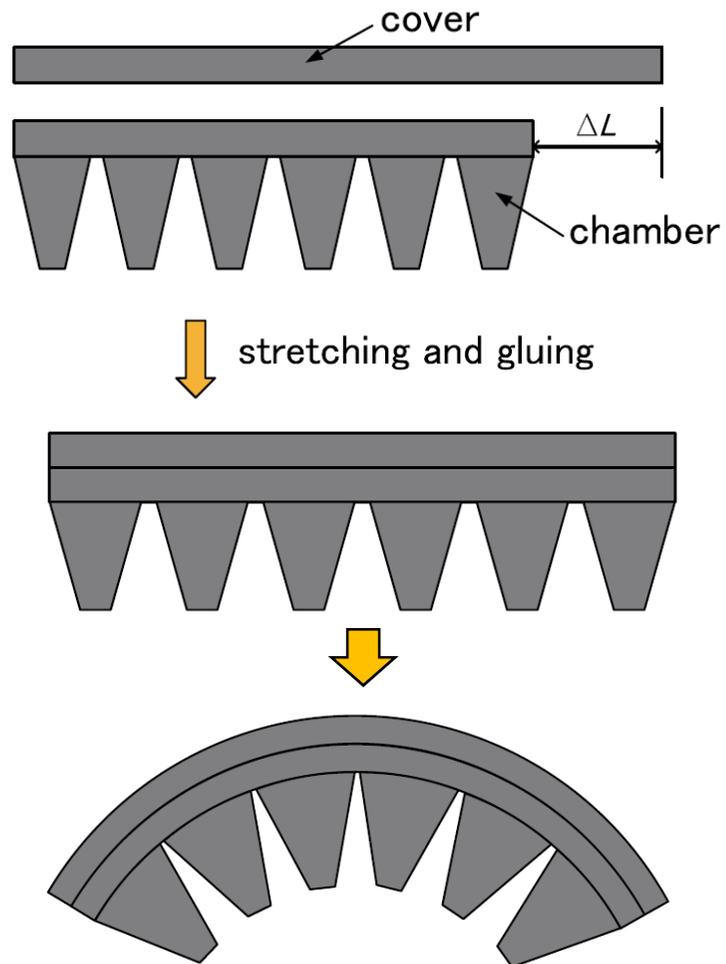
ValoWhite (hard)

TagoBlack+ (soft)

# ソフトグリッパー

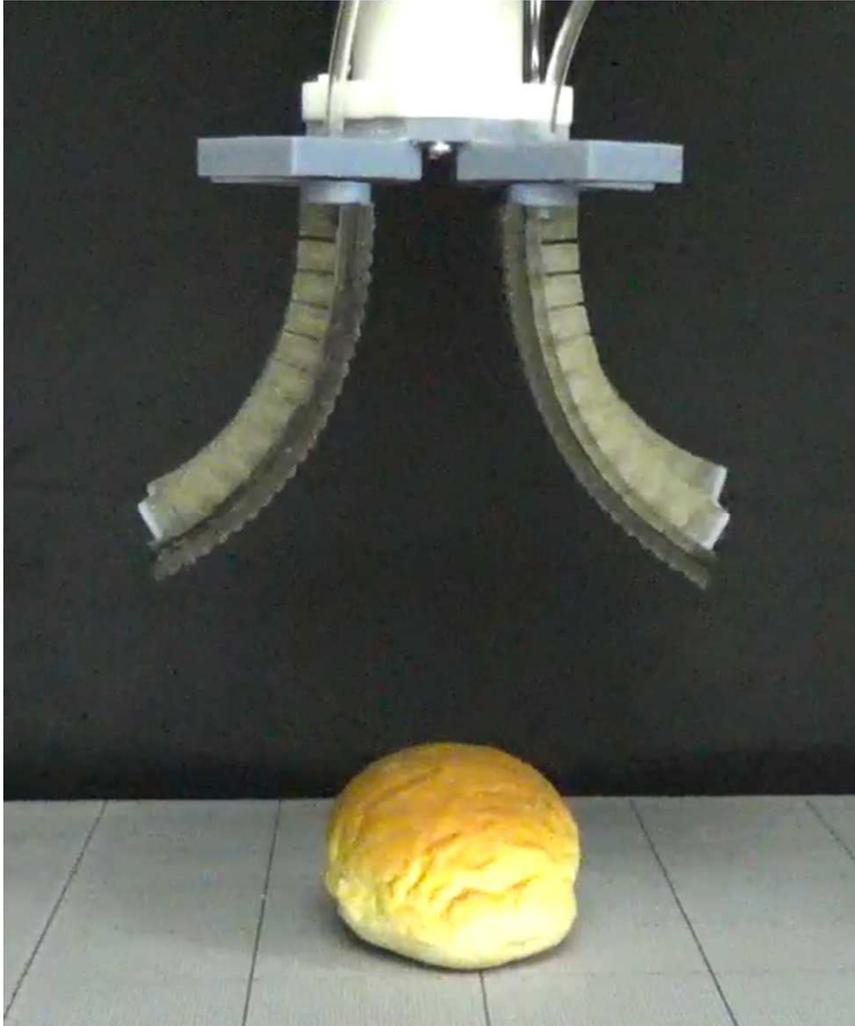


# プレストレッッチハンド

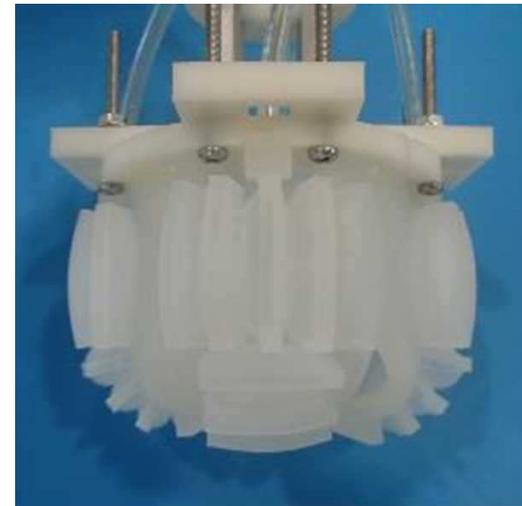
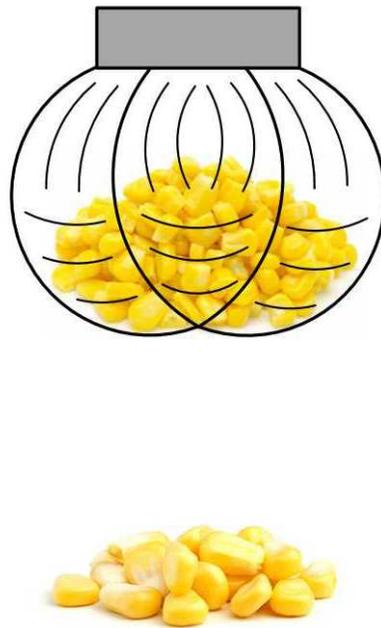
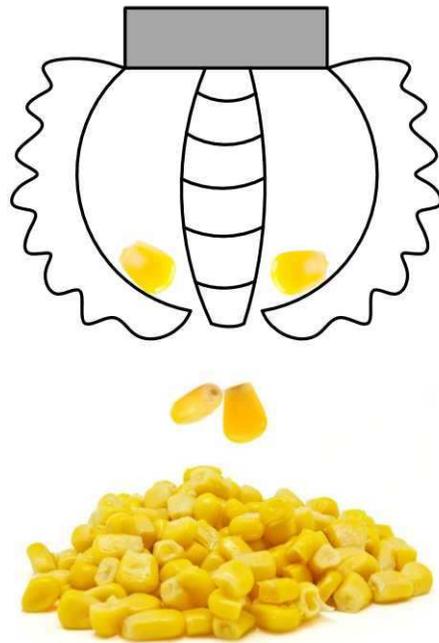


Wang et al., IEEE RAL, 2017

# プレストレッチハンド



# 包みグリッパー

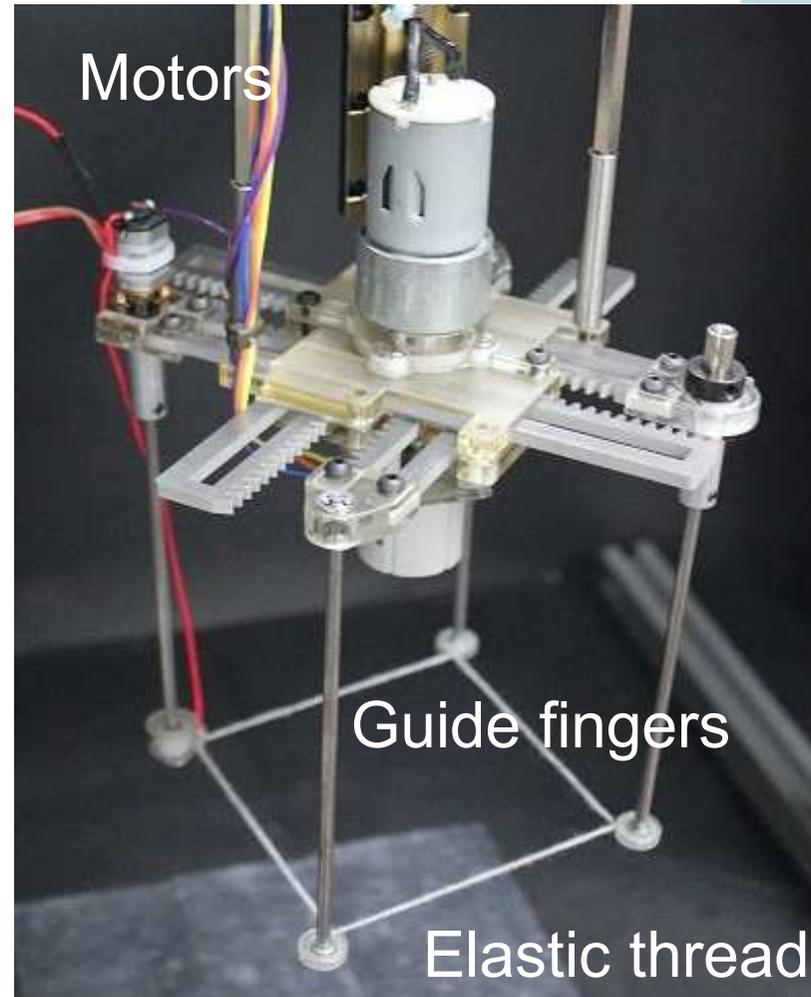


Kuriyama et al., IEEE RoboSoft 2019

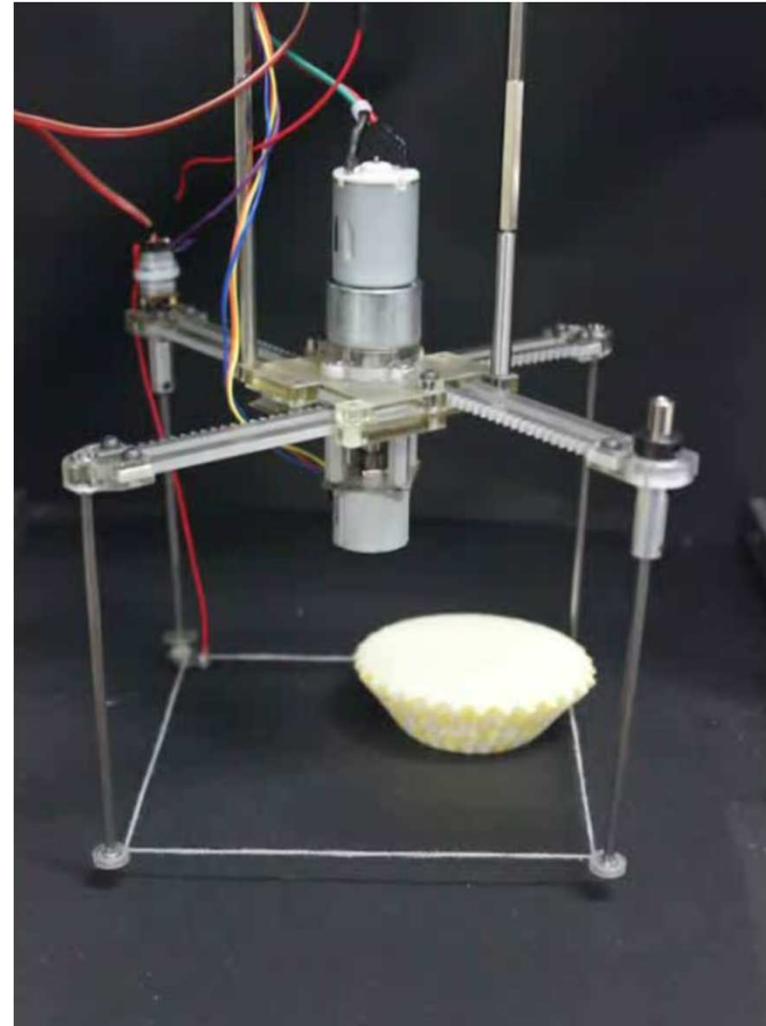
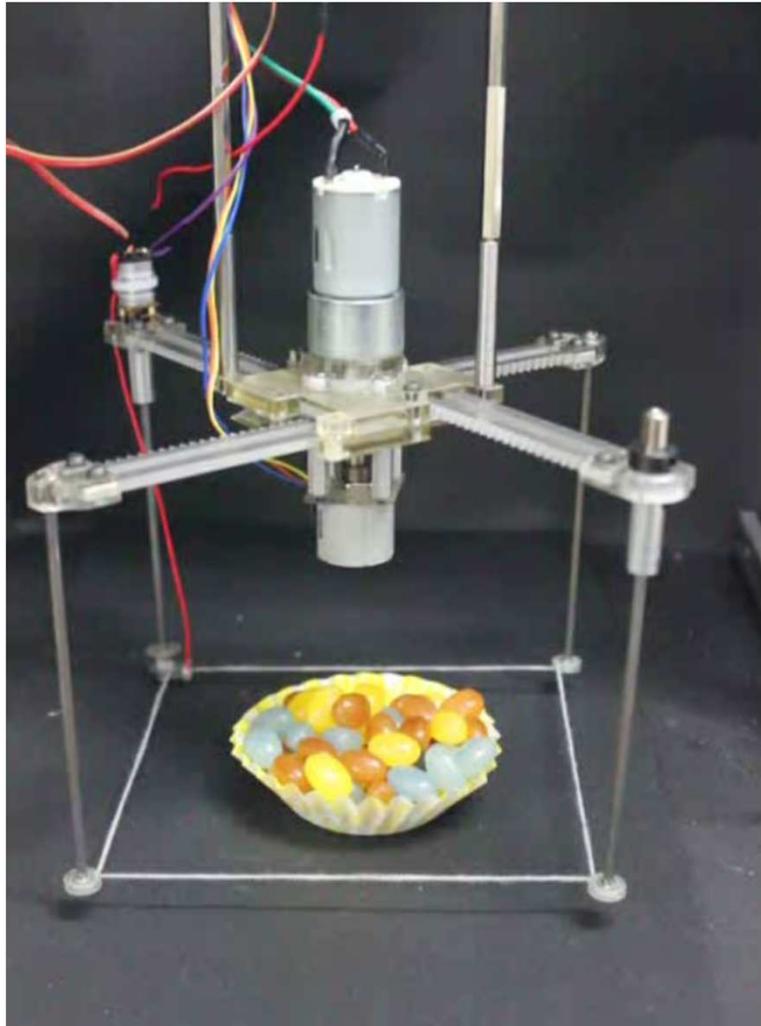
# 包みグリッパー



# バインディングハンド



# バインディングハンド



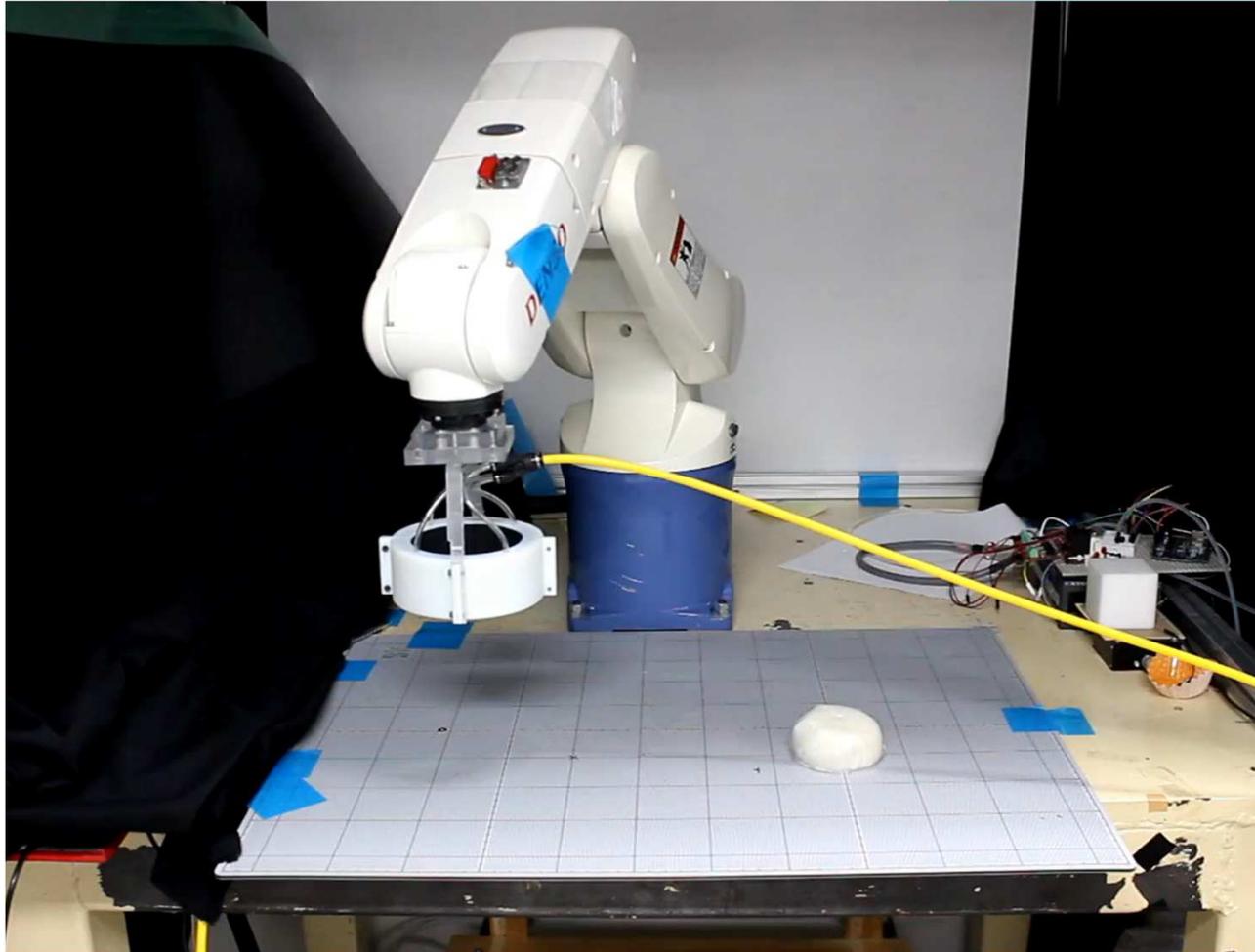
# 環状ソフトグリッパー



Kanegae et al., IEEE RoboSoft 2019

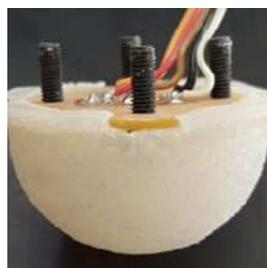
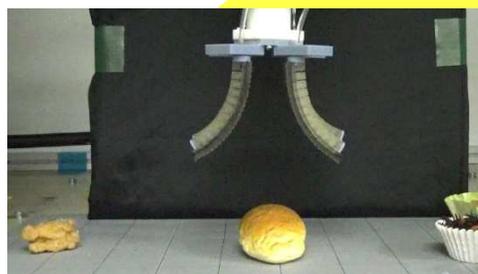
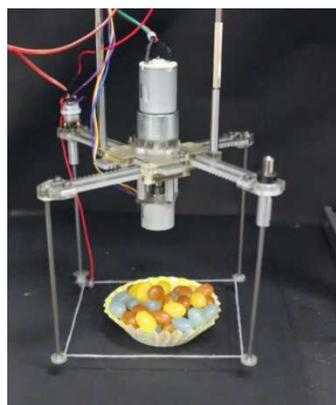
特殊講義 I 2019/4/27

# 環状ソフトグリッパー



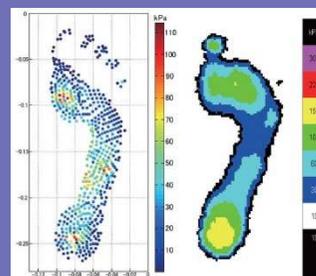
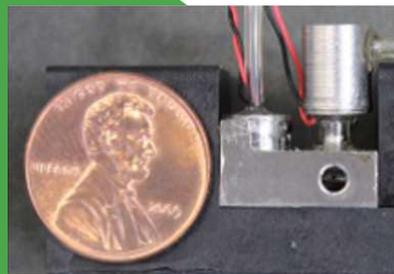
# ソフトロボティクス研究室

## 柔軟物ハンドリング



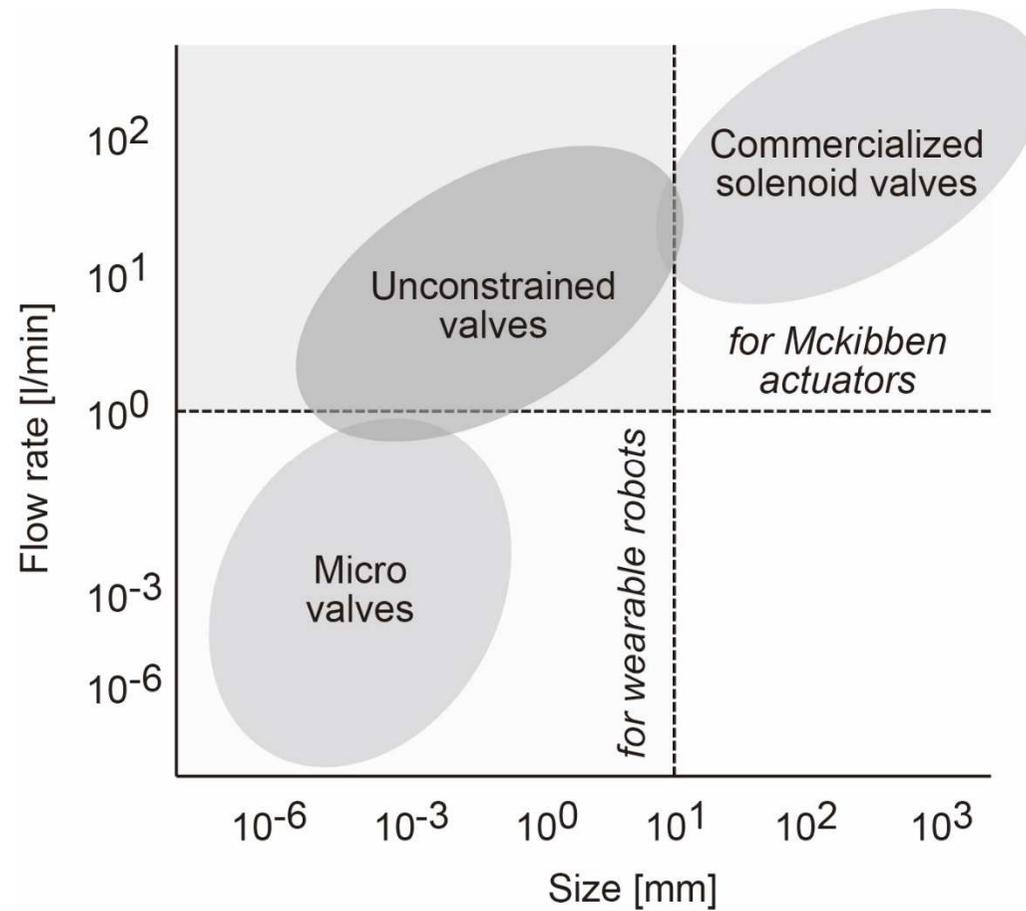
## 触知覚センシング

## 空気圧駆動ロボット

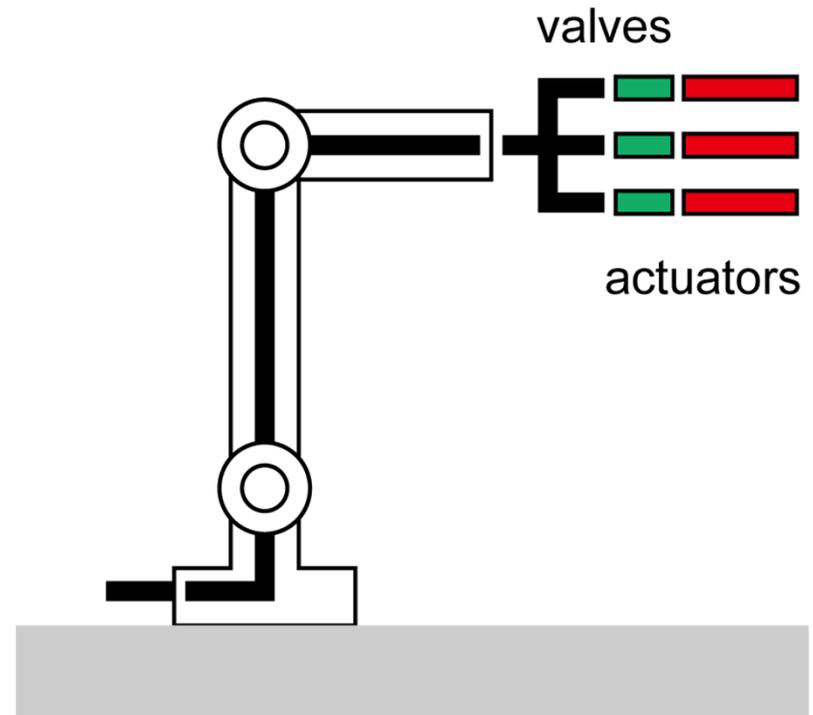
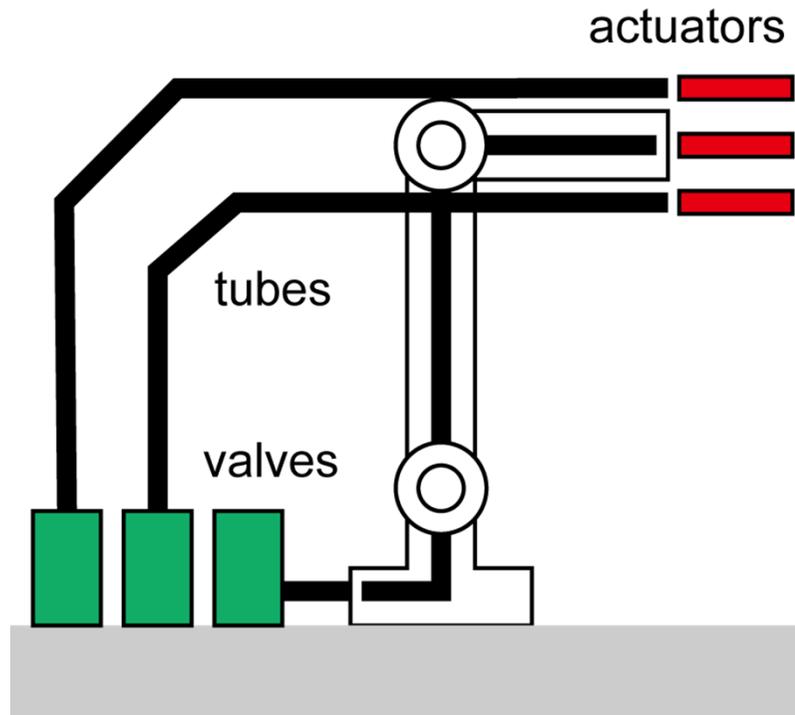


## 人体モデリング

# バルブの現状



# バルブの現状



# 無拘束マイクロ空気圧弁

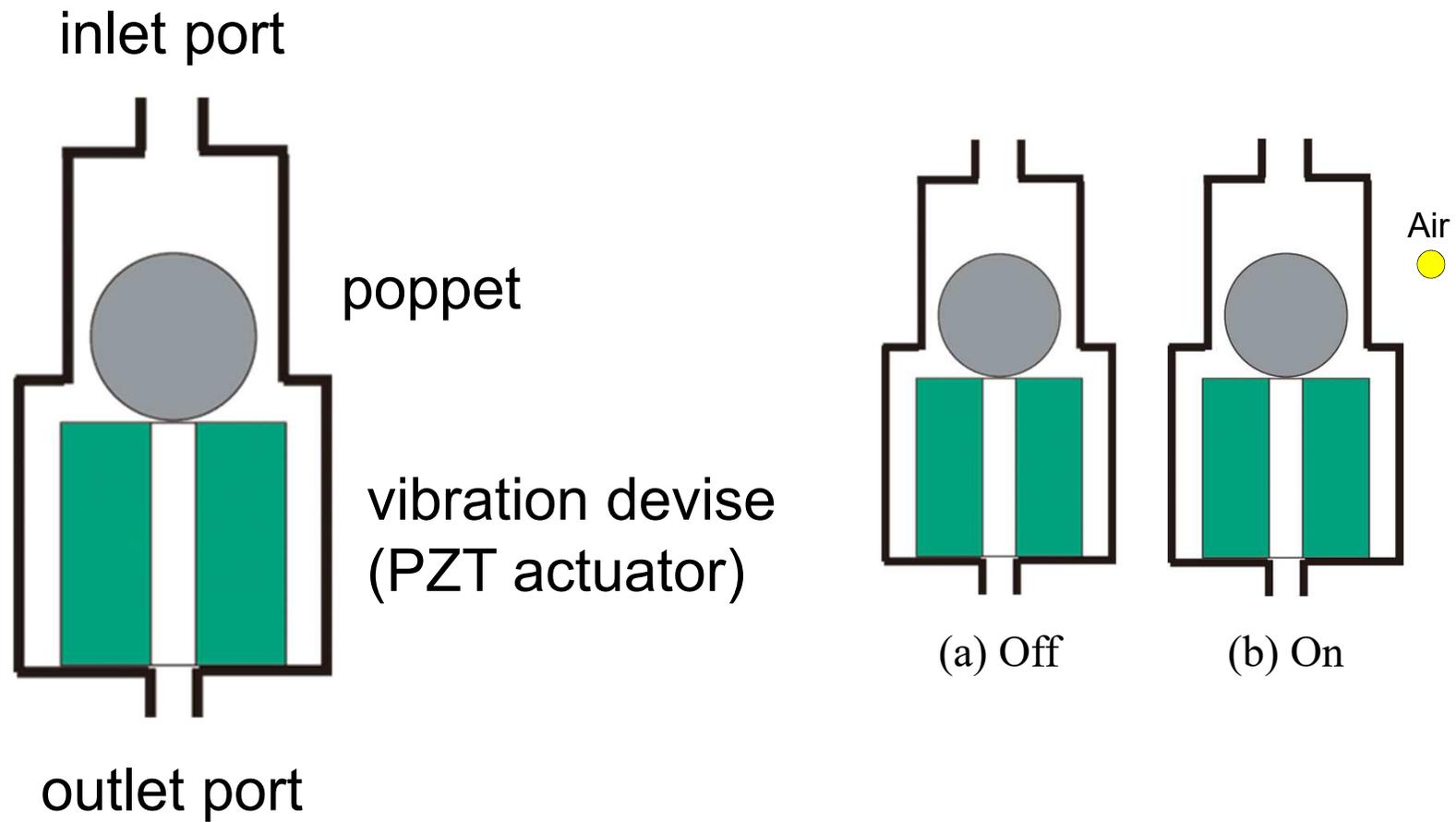


空気圧弁

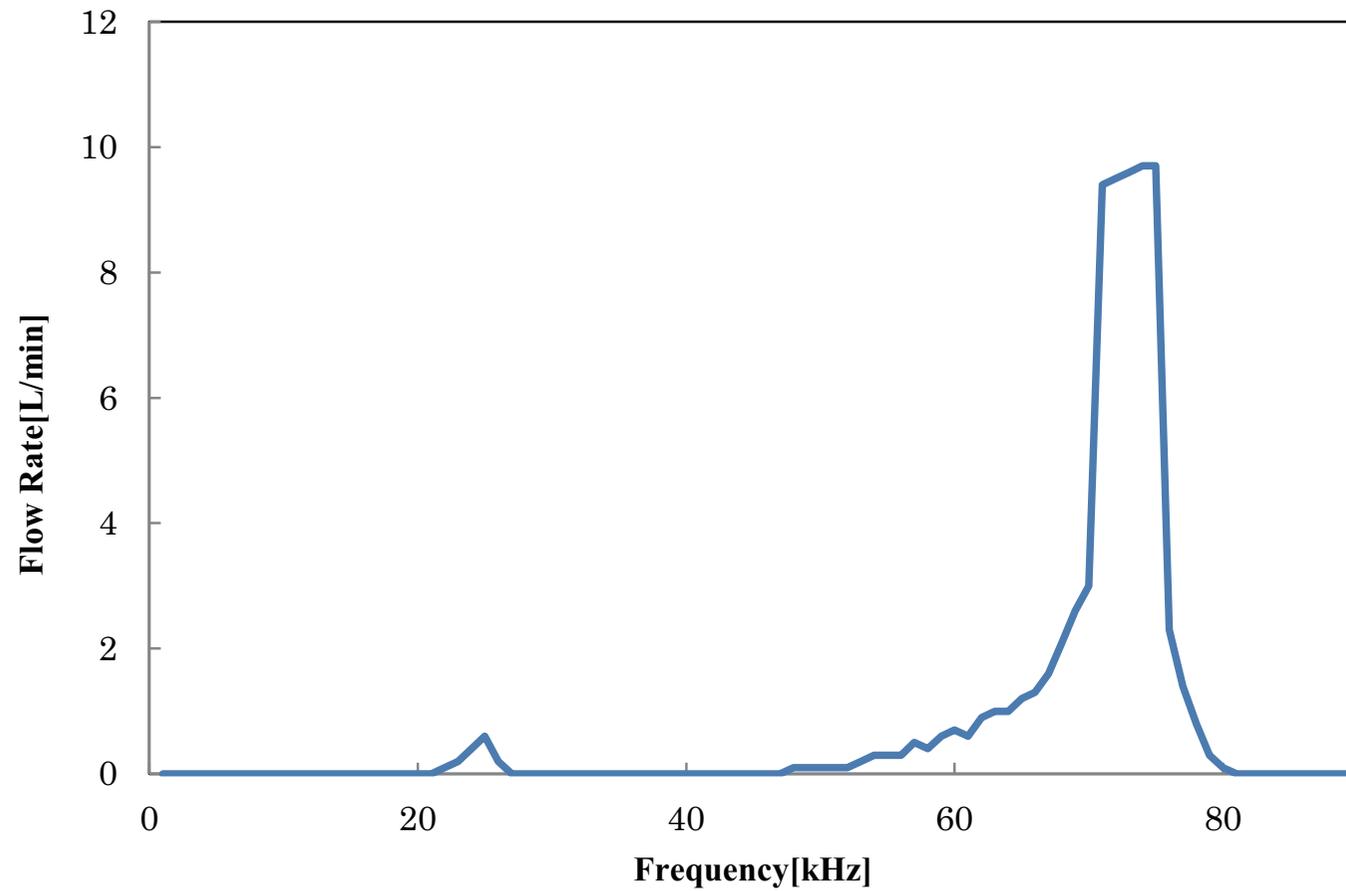


駆動回路

# 原理



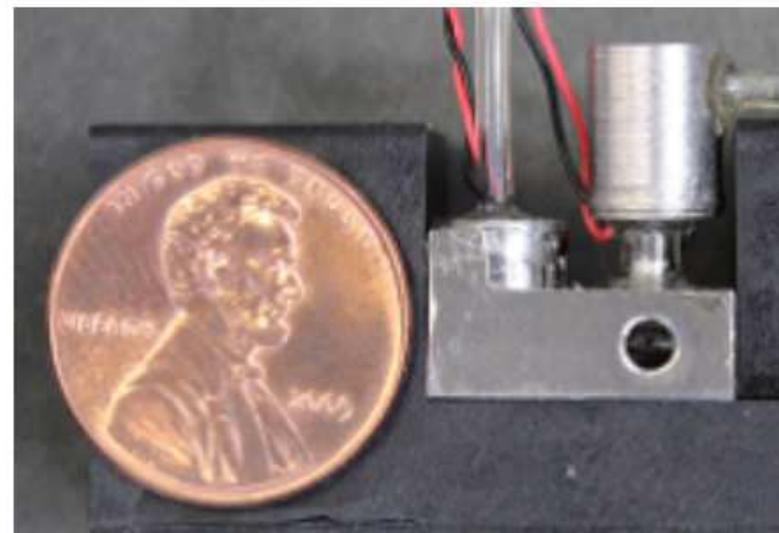
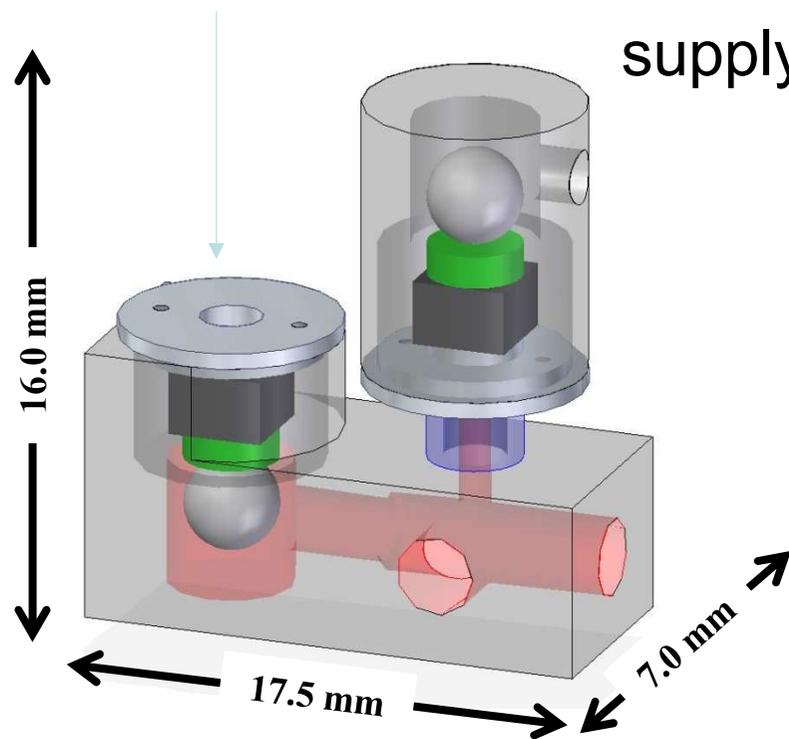
# 驅動周波数 — 流量



# 三方向弁

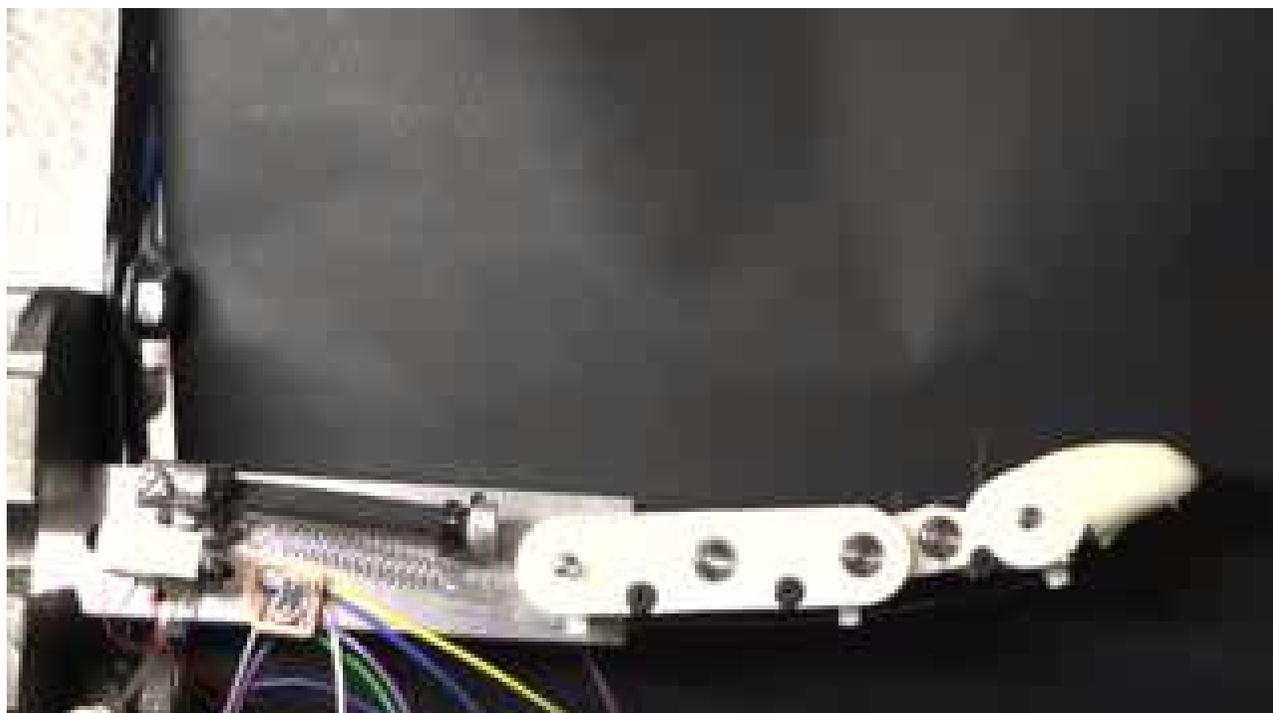
exhaust valve

supply valve

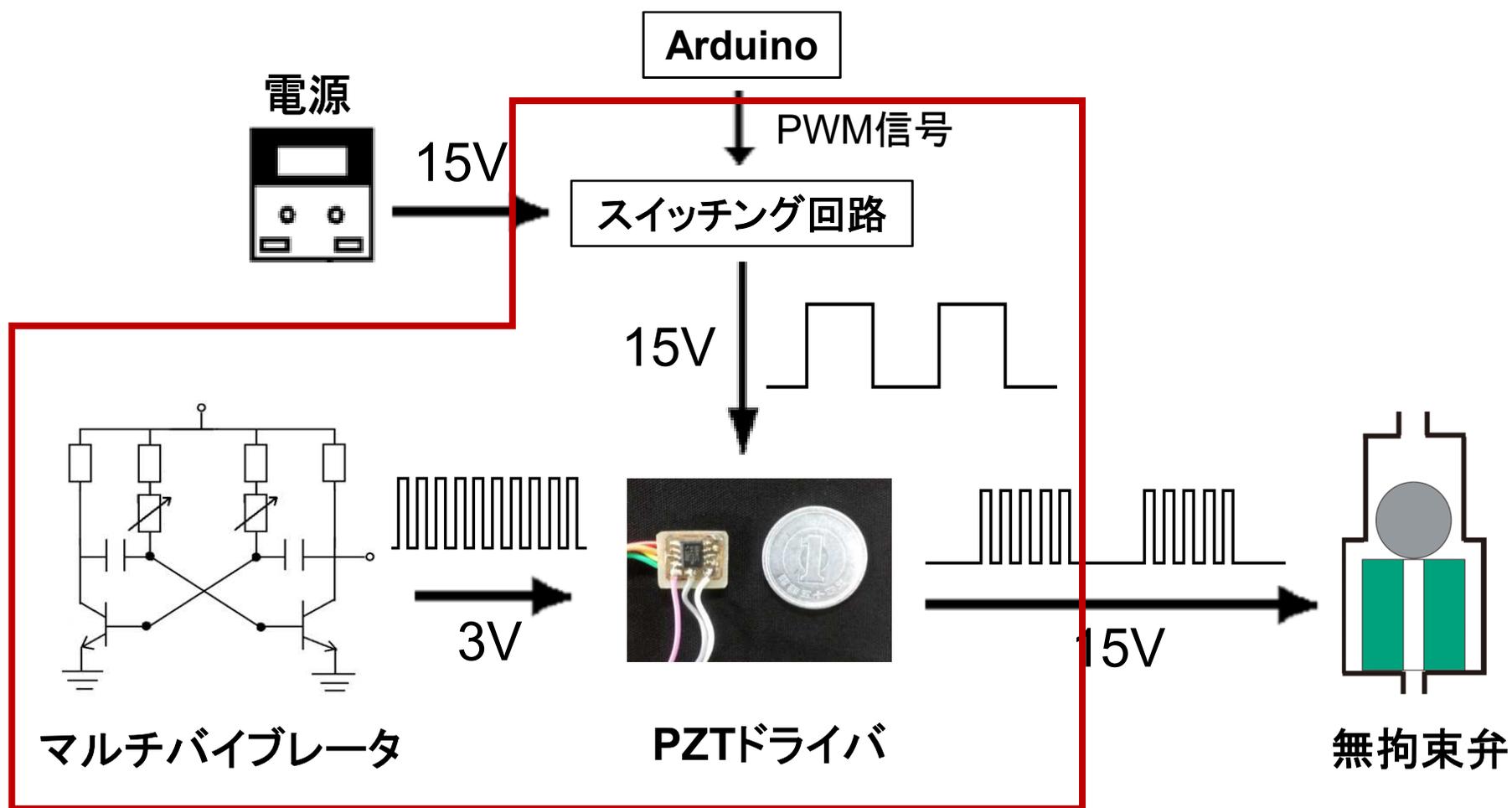


# マッキベンアクチュエータの駆動

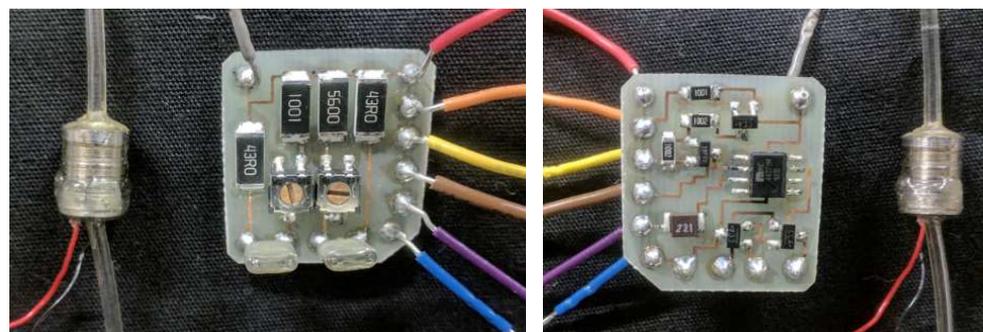
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# 駆動回路

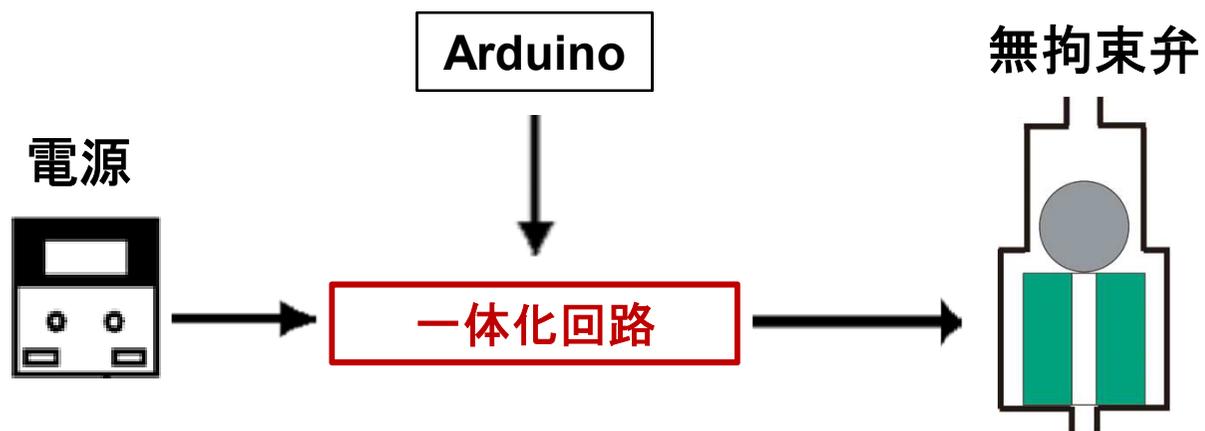


# 驅動回路

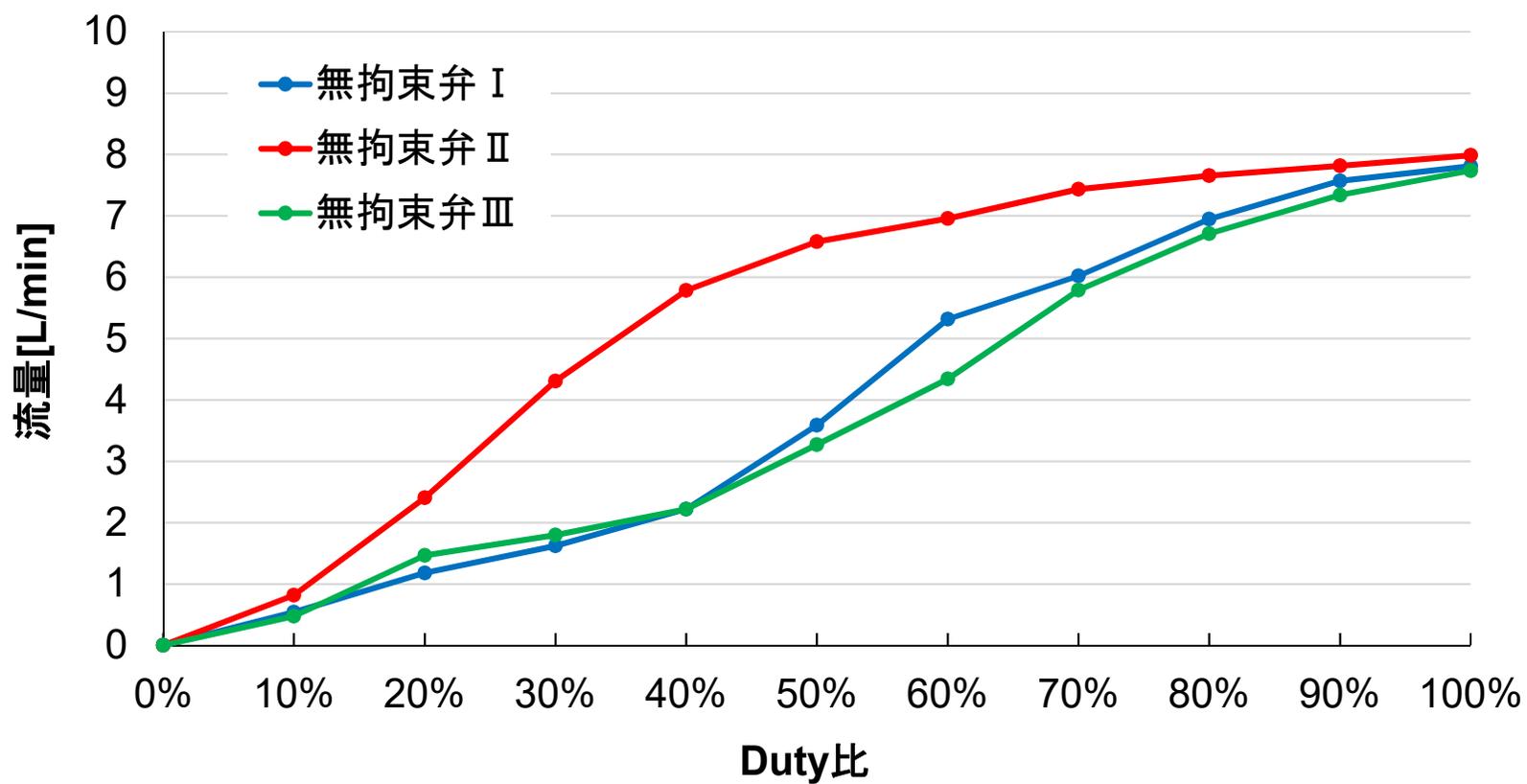


表

裏

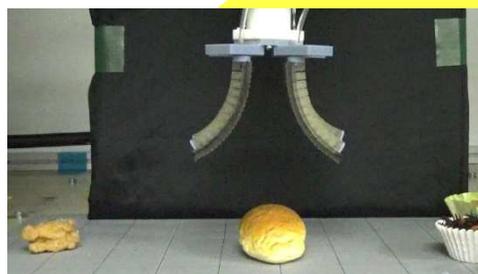
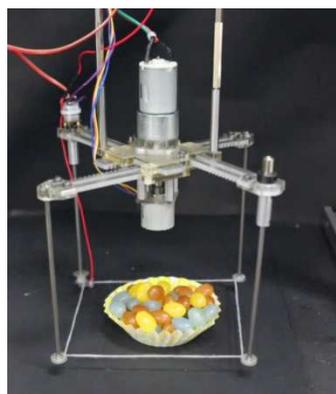


# 驅動回路

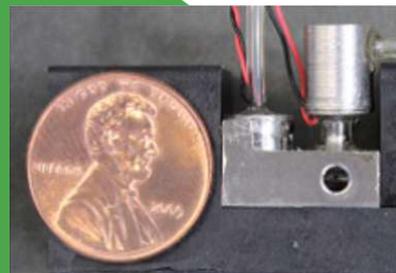


# ソフトロボティクス研究室

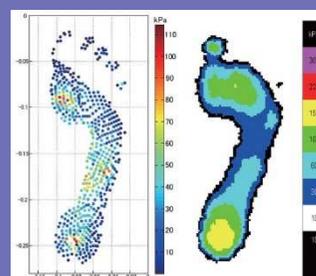
## 柔軟物ハンドリング



## 空気圧駆動ロボット



## 触知覚センシング



## 人体モデリング

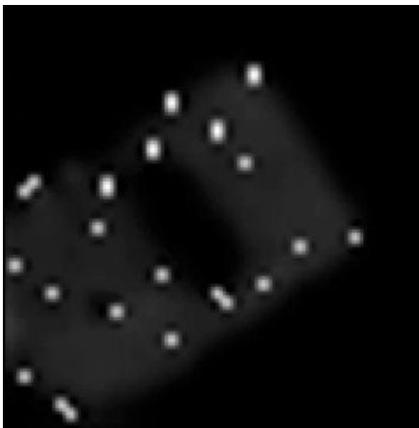
# 触覚センサ



**Micro force/moment sensor**  
Ho, Dao, Sugiyama, Hirai,  
IEEE TRO, 27-3, 2011

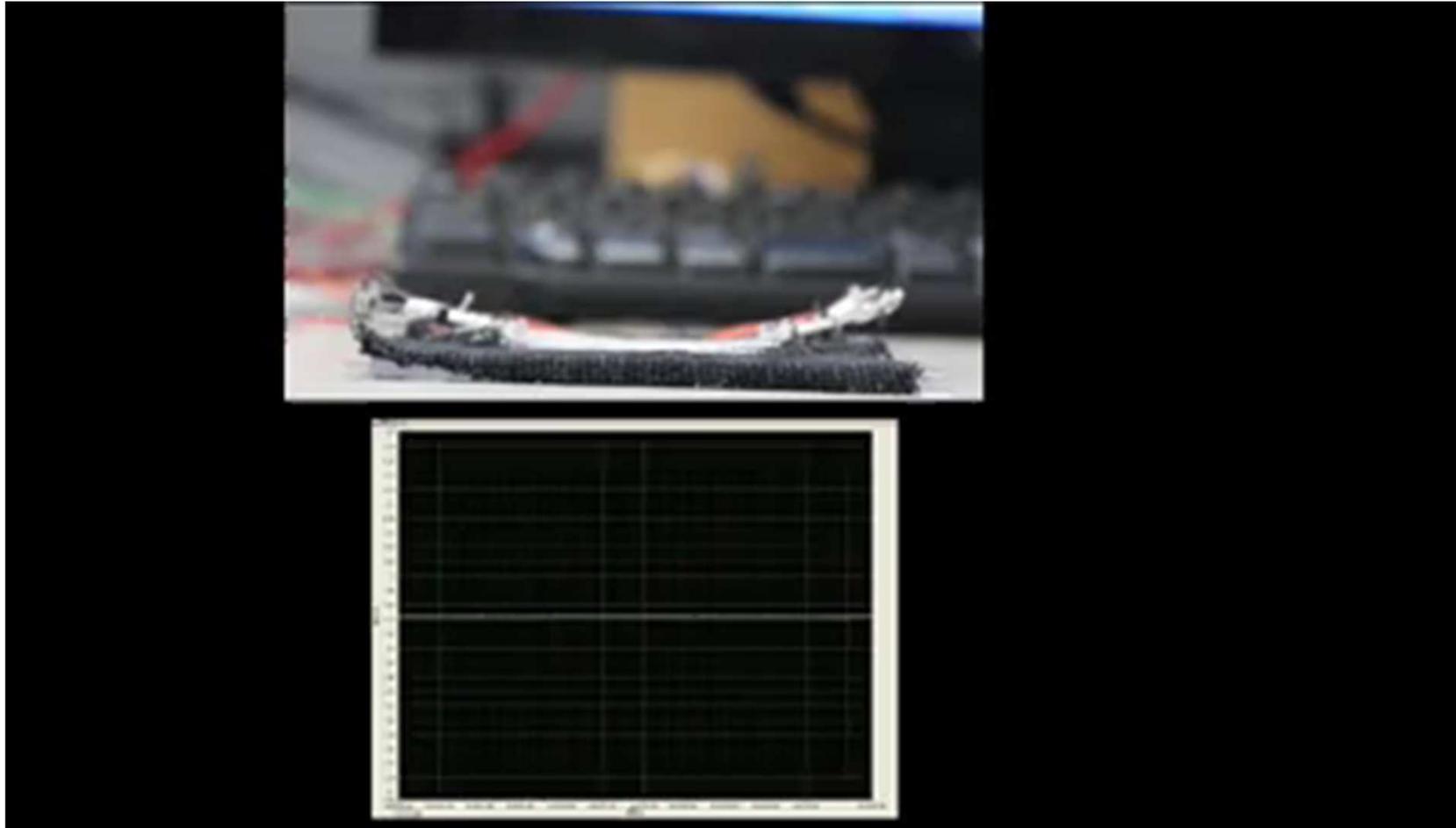


**Fabric Tactile Sensor**  
Ho, Kondo, Okada, Araki, Fujita,  
Makikawa, and Hirai, IEEE/RSJ IROS 2011  
Ho, Araki, Makikawa, Hirai,  
IEEE/RSJ IROS 2012

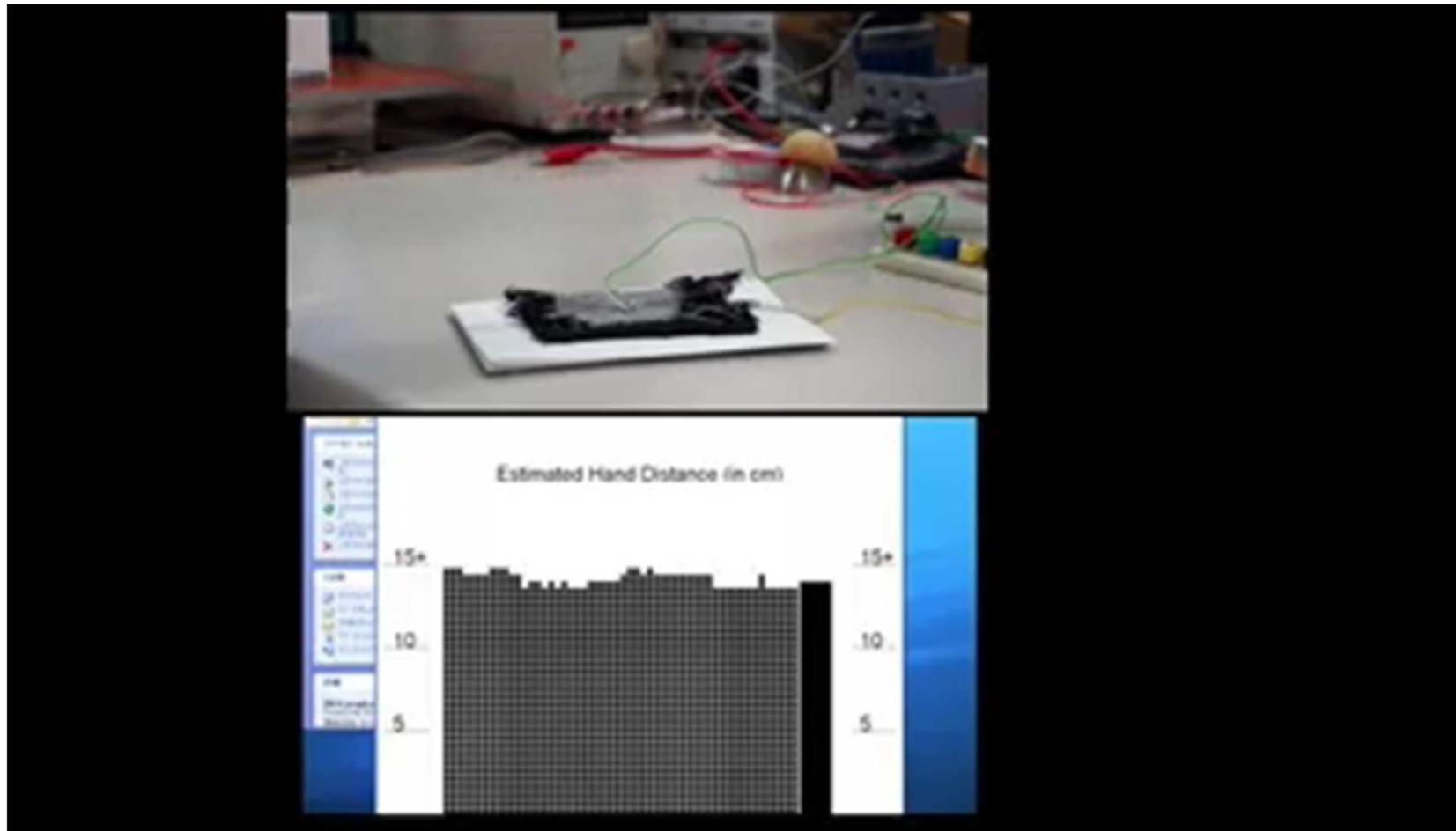


**Tactile image processing**  
Ho, Nagatani, Noda, and Hirai,  
IEEE CASE 2012  
Ho and Hirai, IEEE HRI workshop, 2012

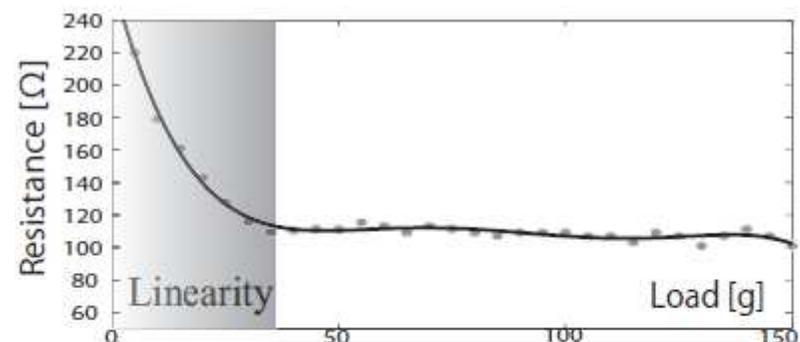
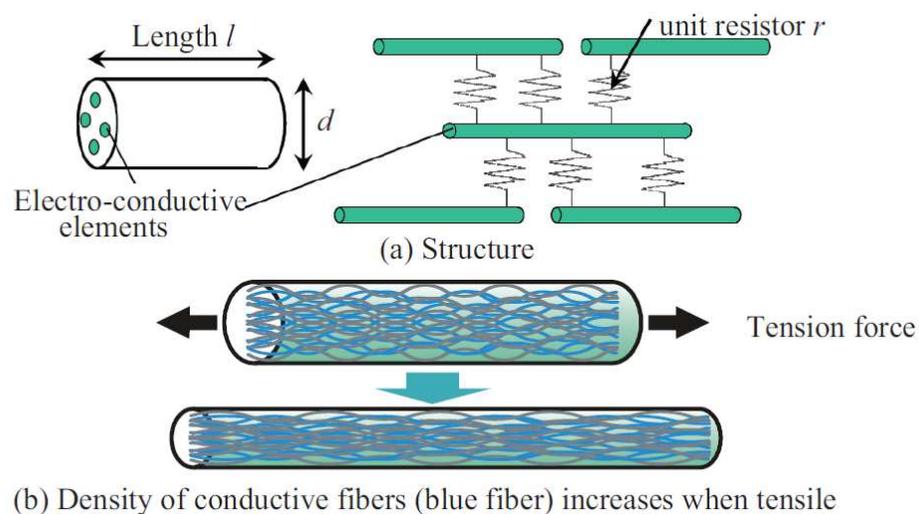
# 布センサ：接触センシング



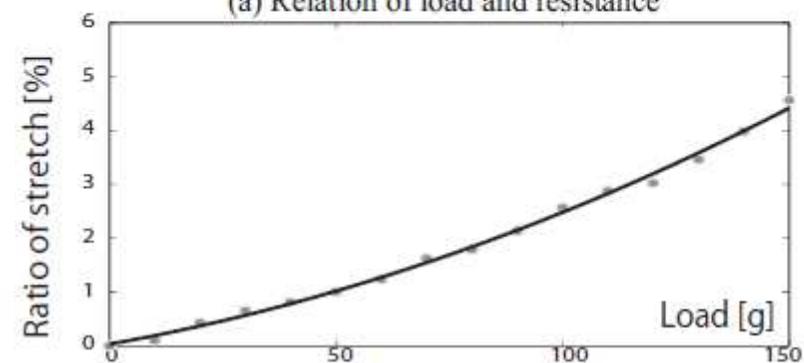
# 布センサ: 近接センシング



# 感圧導電糸



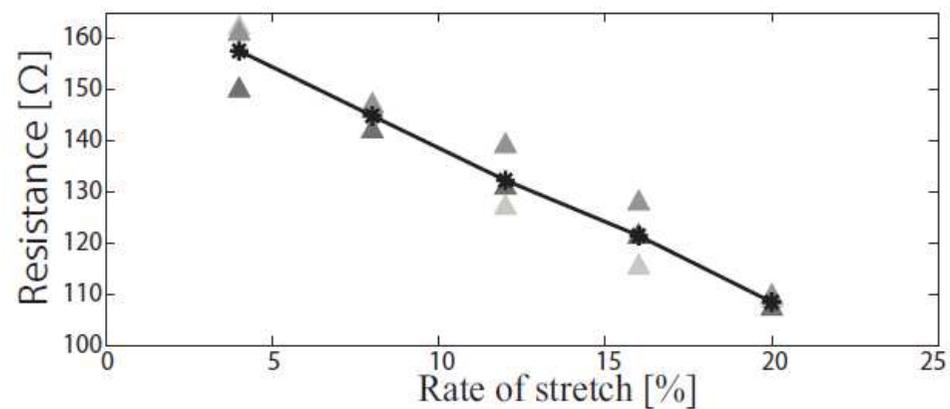
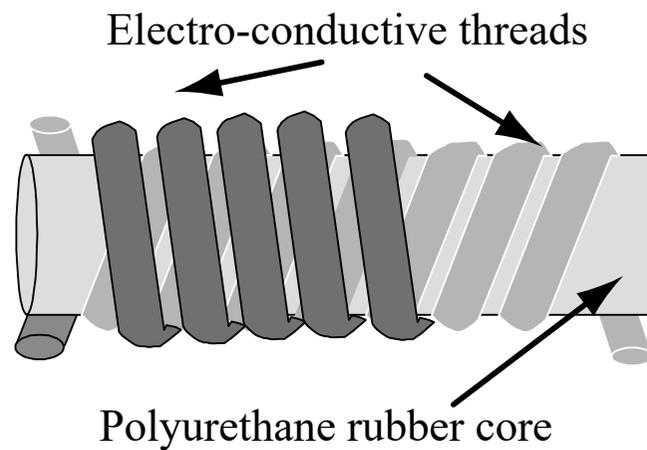
(a) Relation of load and resistance



(b) Relation of load and stretch

計測範囲 ~ 2%

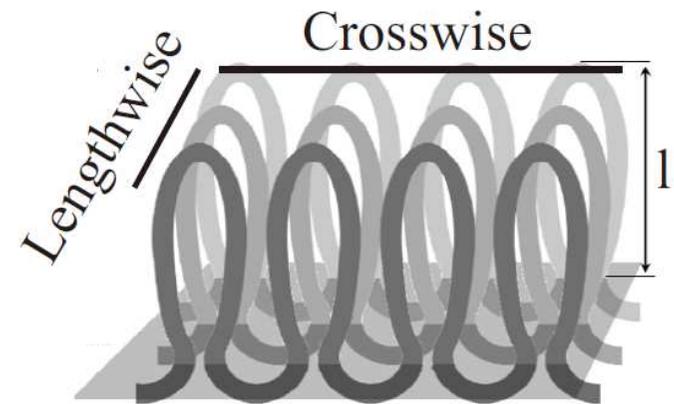
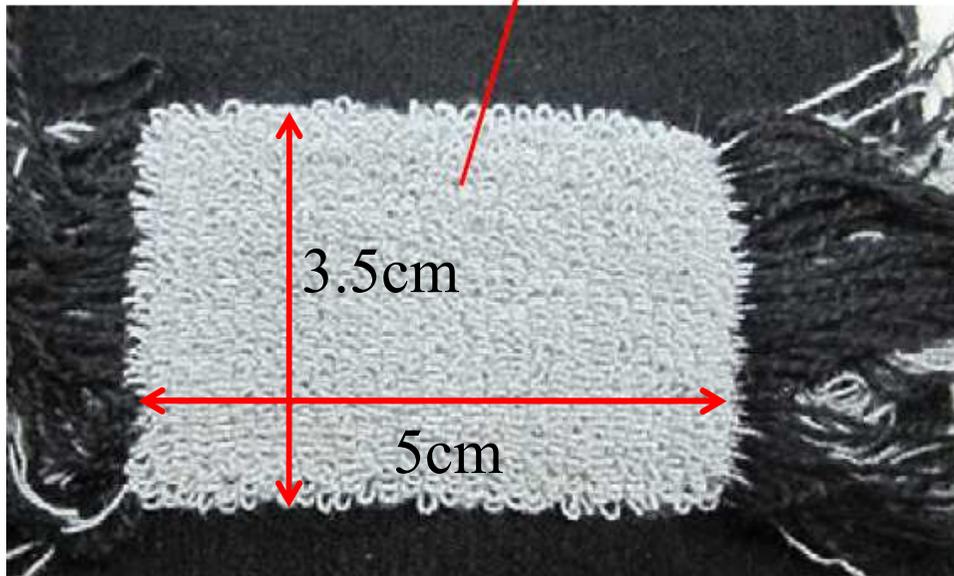
# 感圧導電糸



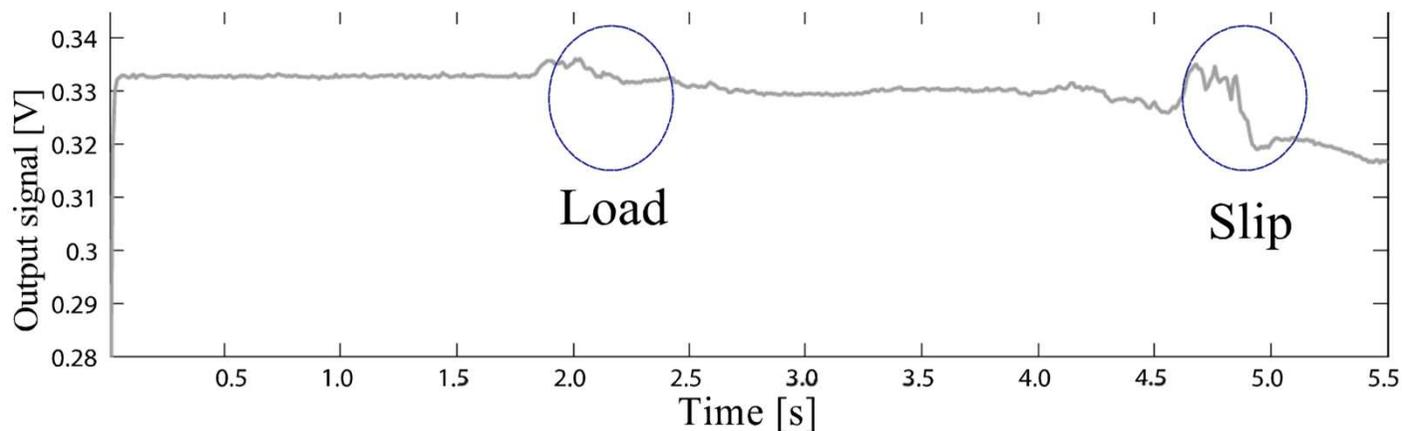
計測範囲 ~ 20%

# 布センサ

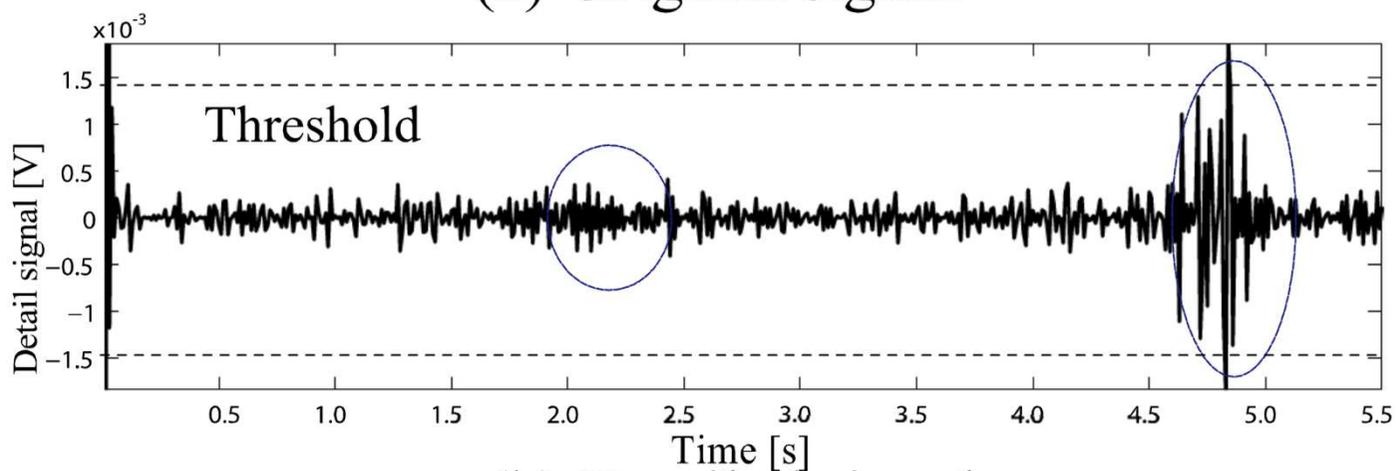
感圧導電糸から成るパイル生地



# 布センサーによる滑りの検出

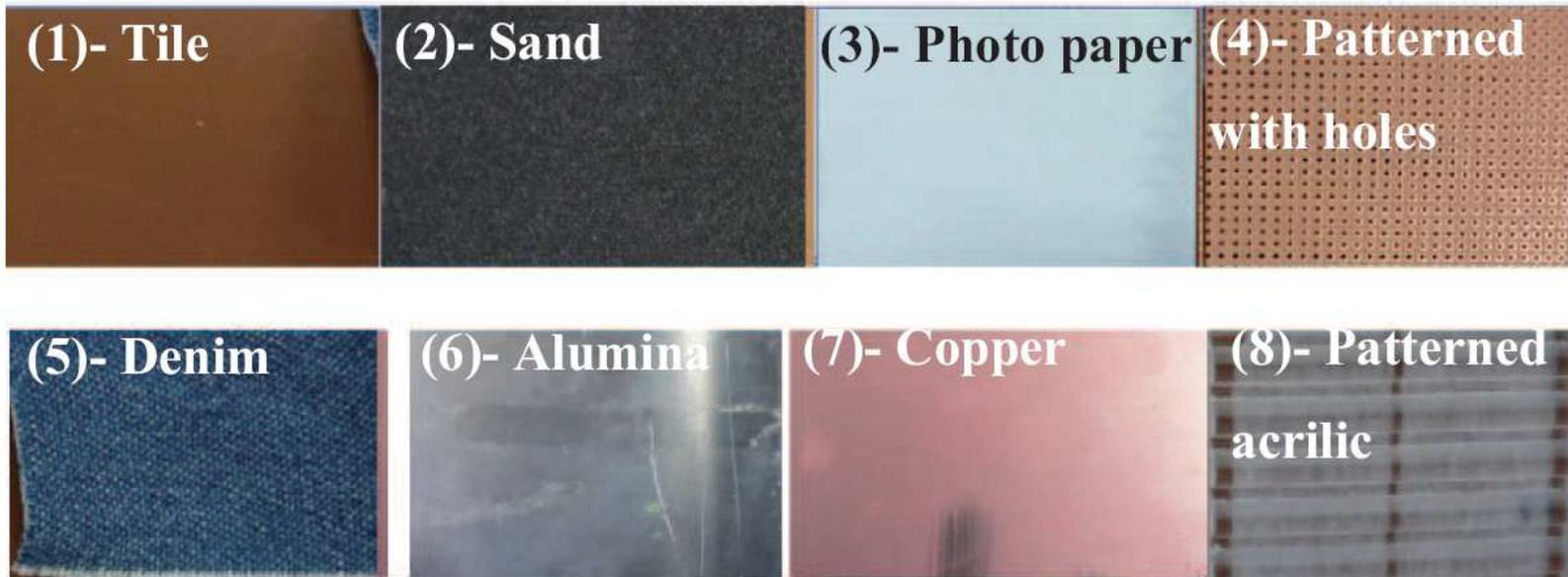
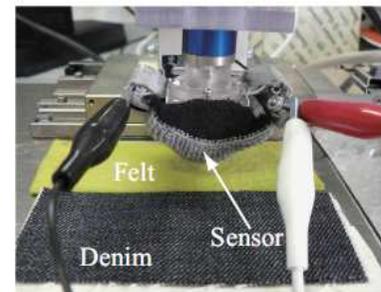
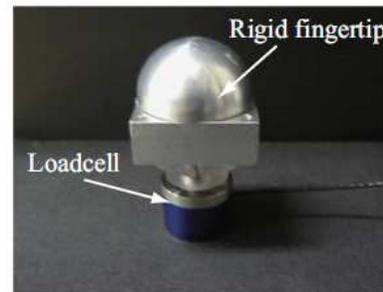


(a) Original signal



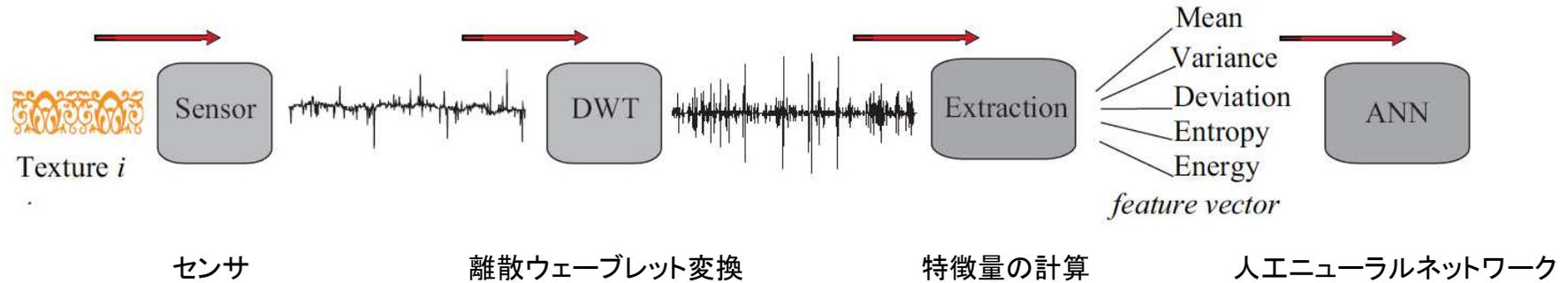
(b) Detailed signal

# テクスチャーの識別

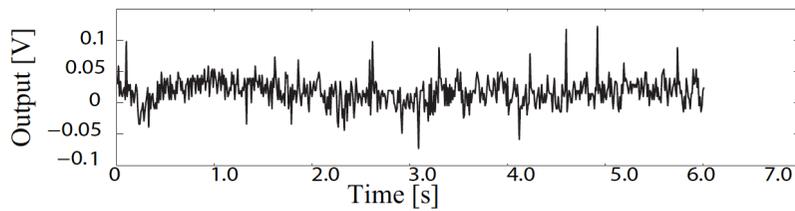


Ho, Makikawa, and Hirai, IEEE Sensors Journal, 2013

# テクスチャの識別

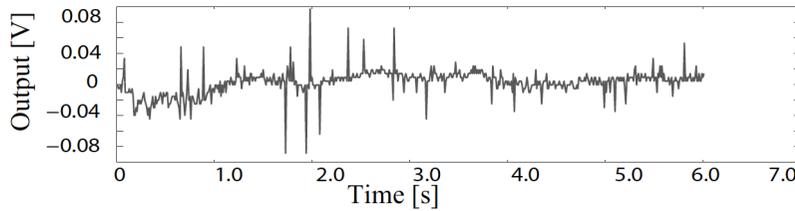


デニム



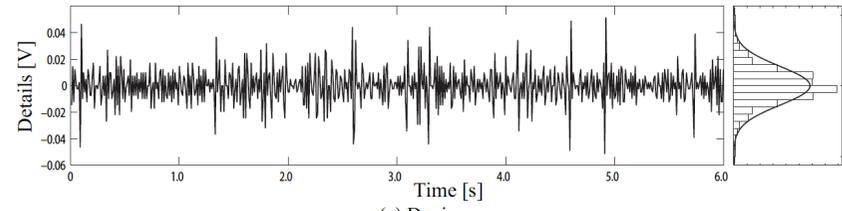
(a) Denim

写真用紙

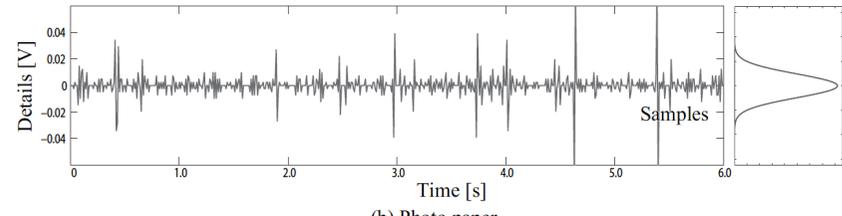


(b) Photo paper

布センサの出力



(a) Denim



(b) Photo paper

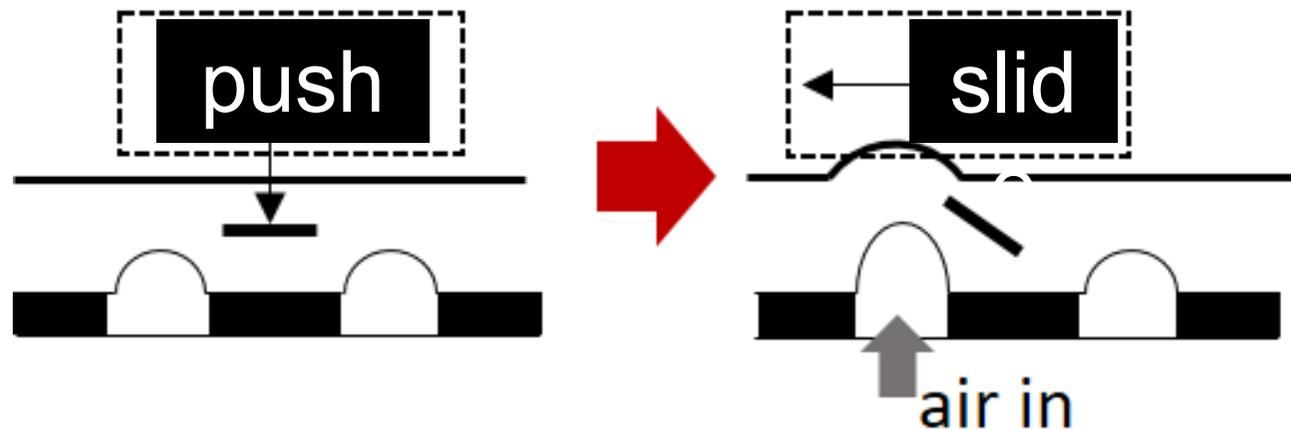
離散ウェーブレット変換の詳細係数

# テキストチャートの識別

		v = 6mm/s								v = 3mm/s								v = 1.5mm/s									
		1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8		
Imm-pile Sensor	1	90	0	0	0	0	0	0	0	1	68	0	0	0	0	0	14	0	1	37	0	0	0	0	0	0	0
	2	0	77	5	0	0	0	0	0	2	0	93	6	0	11	0	0	0	2	0	81	25	0	0	0	0	0
	3	10	11	85	8	0	0	6	0	3	0	7	73	0	13	27	0	0	3	12	0	75	0	0	0	0	0
	4	0	0	0	73	0	0	0	0	4	0	0	0	86	13	0	0	0	4	6.5	7	0	68	31	0	0	0
	5	0	12	5	19	100	0	0	0	5	0	0	12	14	63	0	0	0	5	6.5	12	0	16	56	13	0	0
	6	0	0	0	0	0	80	5	0	6	0	0	9	0	0	73	0	0	6	24	0	0	16	13	87	0	0
	7	0	9	5	0	0	0	89	0	7	32	50	0	0	0	0	86	0	7	0	0	0	0	0	0	100	0
	8	0	0	0	0	0	0	0	100	8	0	0	0	0	0	0	0	100	8	14	0	0	0	0	0	0	100
		Predicted Value								Predicted Value								Predicted Value									
		86.5								80.1								75.0									
2mm-pile Sensor	1	76	0	0	0	10	17	0	1	66	0	9	34	0	0	49	0	1	72.5	12.5	0	6.5	0	0	0	0	
	2	8	61	25	0	0	0	0	2	0	66	25	0	0	0	0	0	2	0	75	6.5	0	15	0	0	0	
	3	0	0	65	0	0	0	0	3	34	0	33	8	25	0	0	0	3	12.5	0	31.5	0	16	0	0	0	
	4	6	8	0	58	31	0	0	4	0	25	18	58	0	0	0	0	4	6.5	0	18.5	50	0	0	0	0	
	5	0	31	10	16	61	13	0	5	0	9	15	0	70	10	9	0	5	8.5	12.5	18.5	18.5	56	10	0	13	
	6	0	0	0	26	8	77	0	6	0	0	0	0	5	100	0	0	6	0	0	0	0	13	90	0	0	
	7	10	0	0	16	0	0	83	0	7	0	0	0	0	0	0	42	0	7	0	0	12.5	6.5	0	0	100	0
	8	0	0	0	0	0	0	0	100	8	0	0	0	0	0	0	0	100	8	0	0	12.5	18.5	0	0	0	87
		Predicted Value								Predicted Value								Predicted Value									
		72.5								66.3								69.5									

識別率85%程度を達成

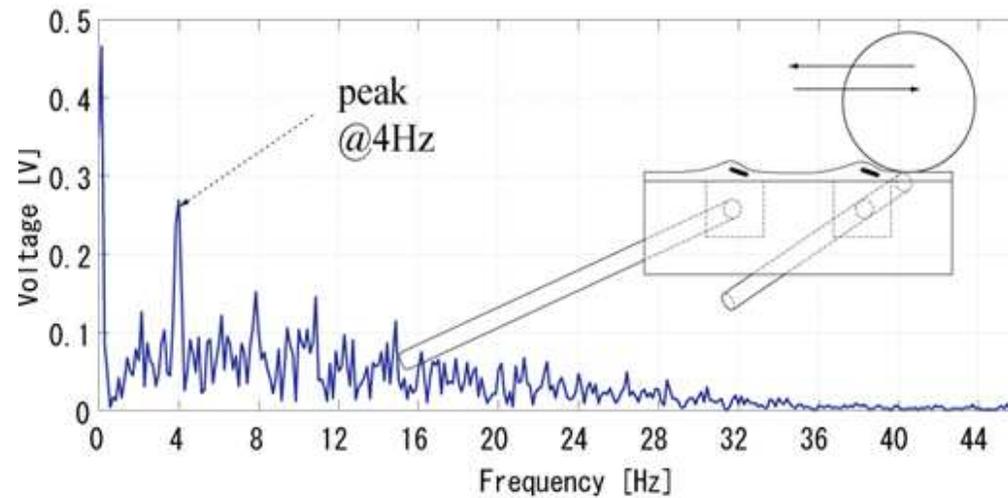
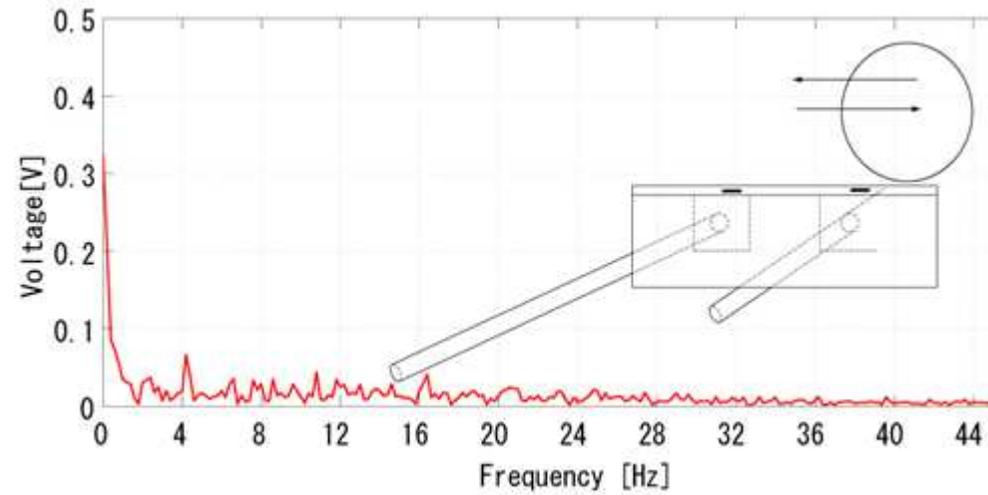
# 滑りセンシング



ストレインゲージの向きを変え、押しと滑りを検出

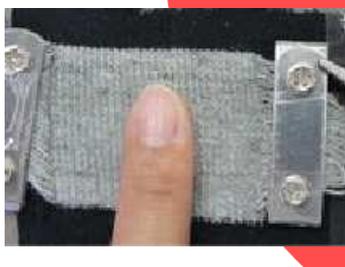
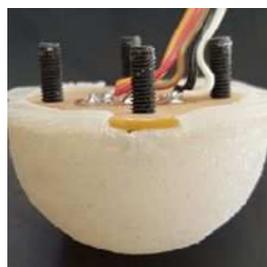
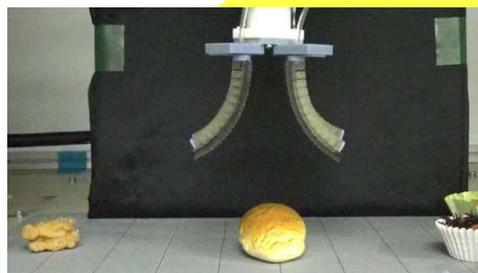
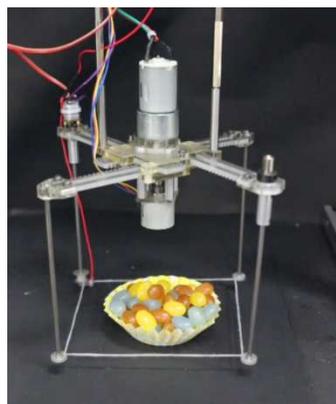
Ho et al., IEEE Trans. Ind. Info., 2017

# 滑りセンシング



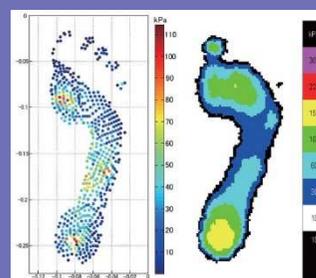
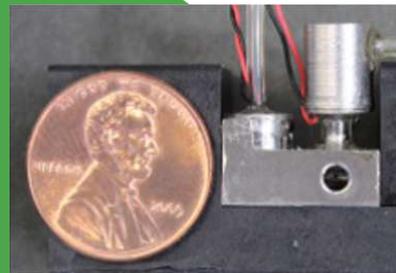
# ソフトロボティクス研究室

## 柔軟物ハンドリング



## 触知覚センシング

## 空気圧駆動ロボット



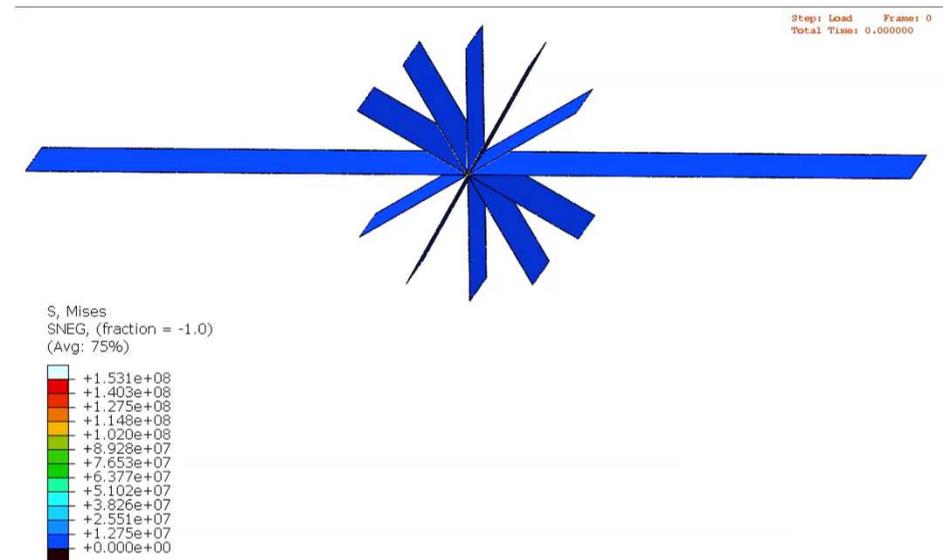
## 人体モデリング

# ソフトロボティクスの確立には

## ファブリケーションとモデリング



Objet360 Connex (Stratasys)



ABAQUS + MATLAB

# ソフトロボティクスの確立には

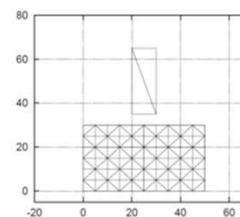
## 力学的解析

フックの法則  $\sigma = E\varepsilon + c\dot{\varepsilon}$

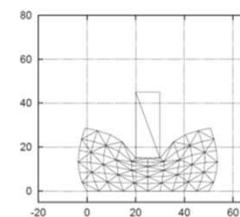
マックスウェルの関係  $\dot{\sigma} + \frac{E}{c}\sigma = E\dot{\varepsilon}$

三要素 (直列)  $\dot{\sigma} + \frac{E}{c_1 + c_2}\sigma = \frac{c_1 c_2 \ddot{\varepsilon} + E c_2 \dot{\varepsilon}}{c_1 + c_2}$

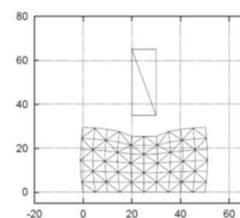
(並列)  $\dot{\sigma} + \frac{E}{c_1}\sigma = c_2 \ddot{\varepsilon} + \frac{E(c_1 + c_2)}{c_1} \dot{\varepsilon}$



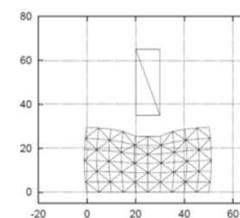
(a) 0 s



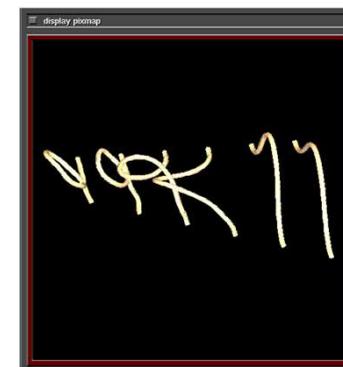
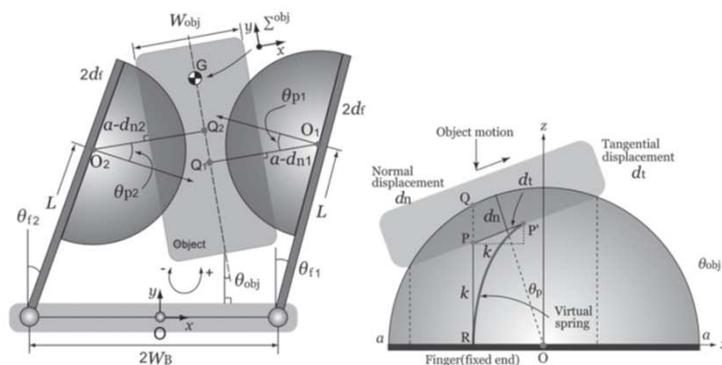
(b) 10 s



(c) 20 s



(d) 30 s



# レポート課題

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ある食材・食品(おかず, 麺類, 菓子, 野菜など)を箱詰めする.  
その作業を実現するロボットシステムを構想し, ハンドやアーム  
の機構や材料, センサや情報処理について検討せよ.