Extended Tactile Perception:
Vibration Sensing through Tools and Grasped Objects

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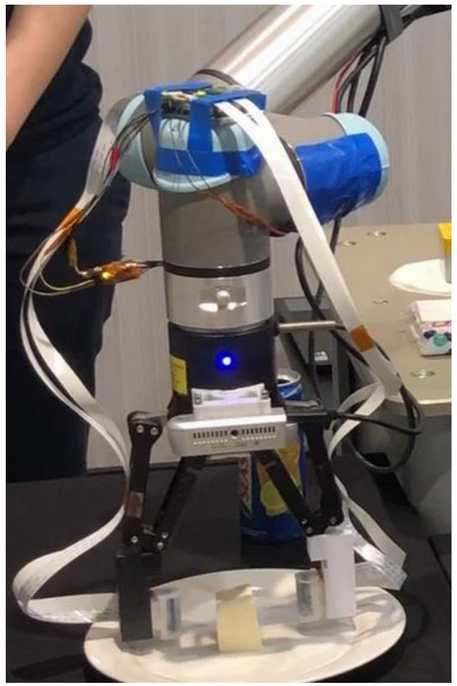
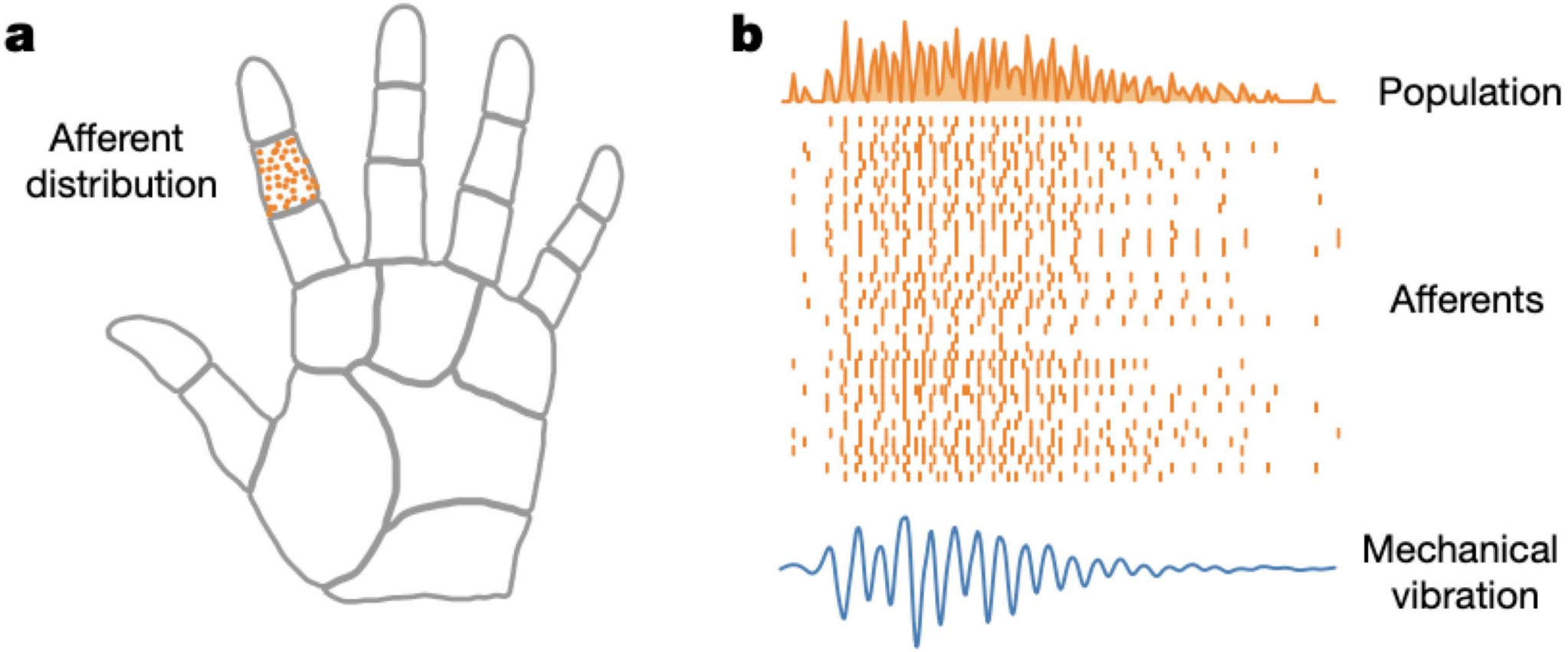
Funding Acknowledgement:

Extended Tactile Perception

Direct Contact



Indirect Contact



[Miller *et al*, Nature 2018]

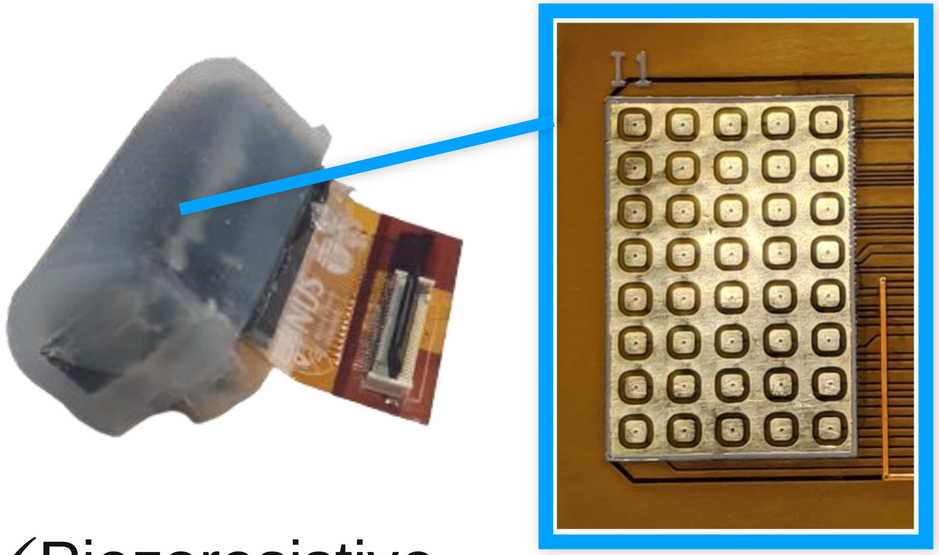
Can robots use tools (and other grasped objects) to
extend their perception
via ***vibro-tactile sensing*** *and* ***learning****?*

Dynamic Tactile Sensors

BioTac PAC

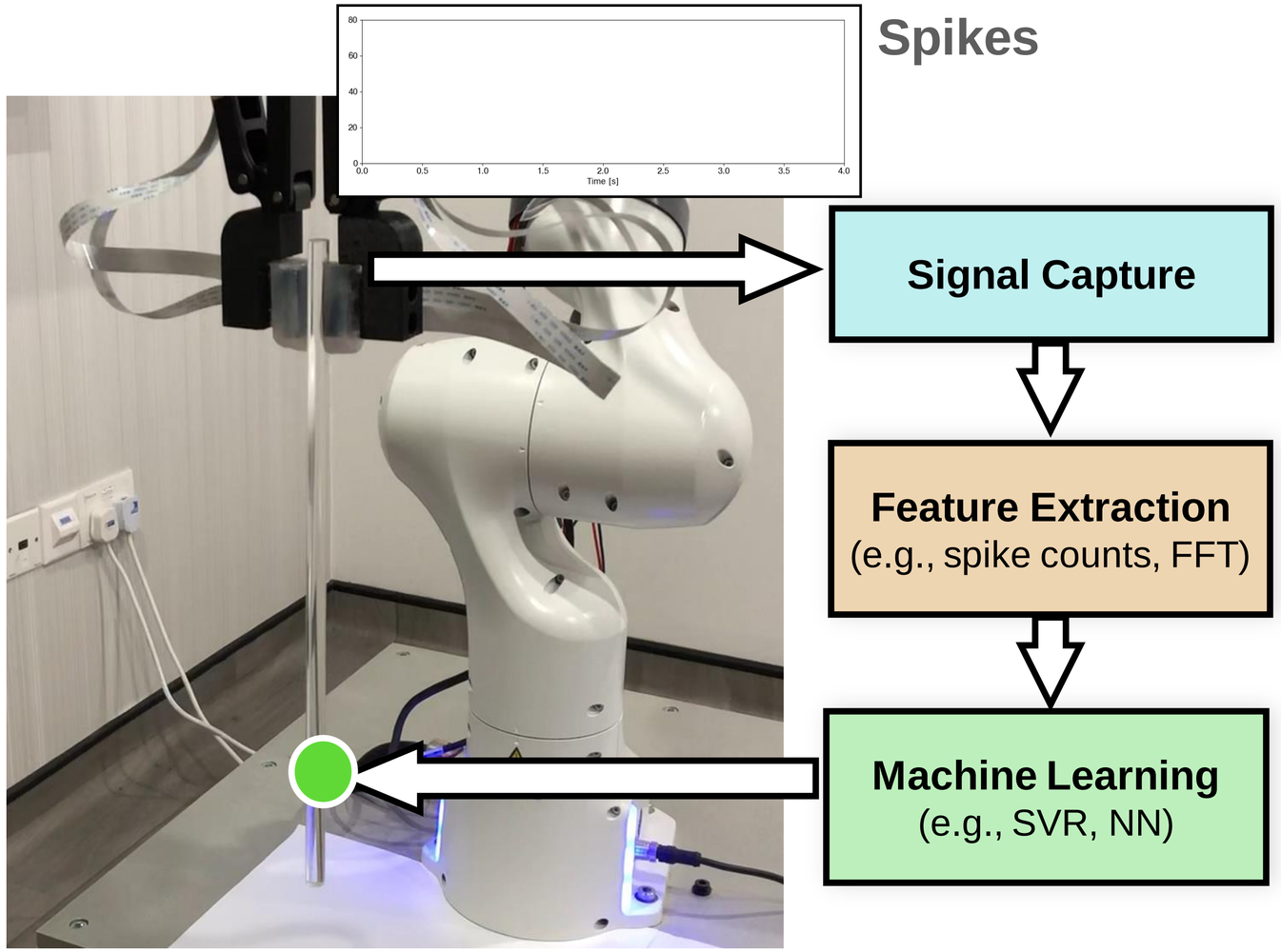
✓Hydrophonic
✓Clock based
✓2200Hz

NUSkin



✓Piezoresistive
✓Asynchronous
✓Up to 4000Hz

A Machine Learning Approach



Models and Feature Types

Models

- Support Vector Machine (Linear kernel)
- Support Vector Machine (RBF kernel)
- Multilayer Perceptron
- Recurrent Neural Network + Multilayer Perceptron

Features

- Spike Counts
- Fast Fourier Transform (FFT)
- Autoencoder
- Event Spike Tensor

Experiment Objectives

Can the robot **localize contacts**?

How **fast** do we need to **sample**?

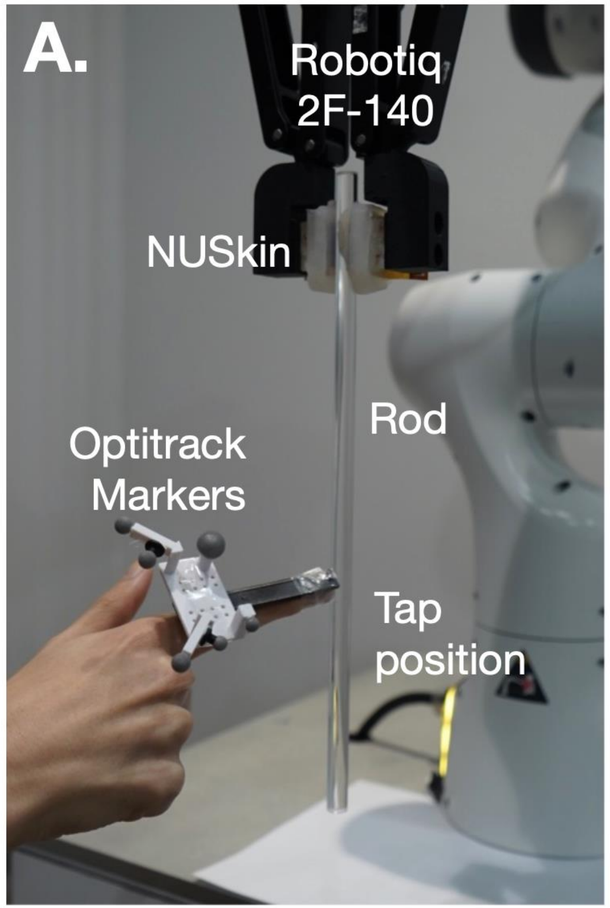
Do we need **multiple taxels**?

Can we **identify stable grasps** during robot-human handover?

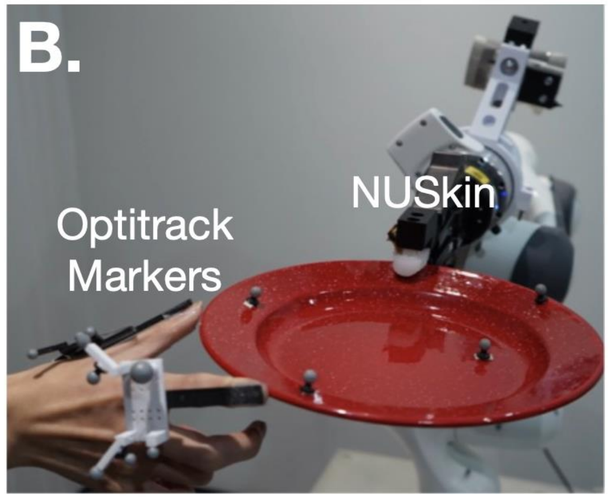
Can we **identify foods** using a regular fork?

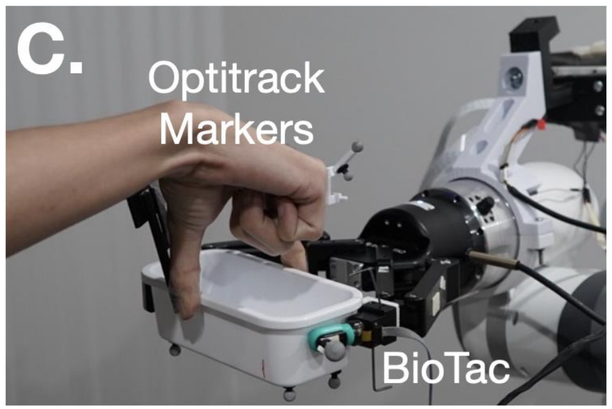
Sensory Extension Tasks

Tap Localization

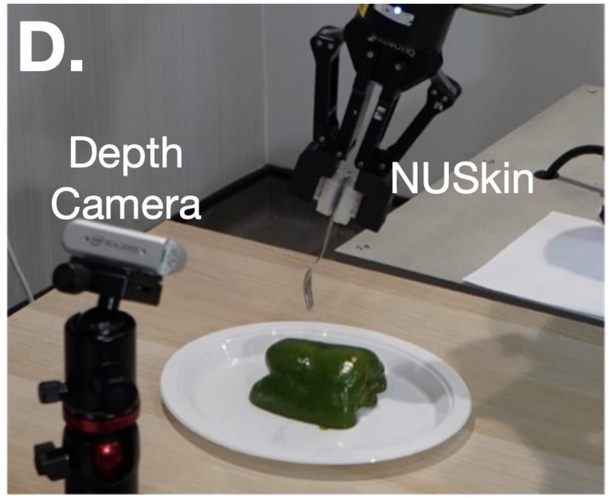


Grasp Stability



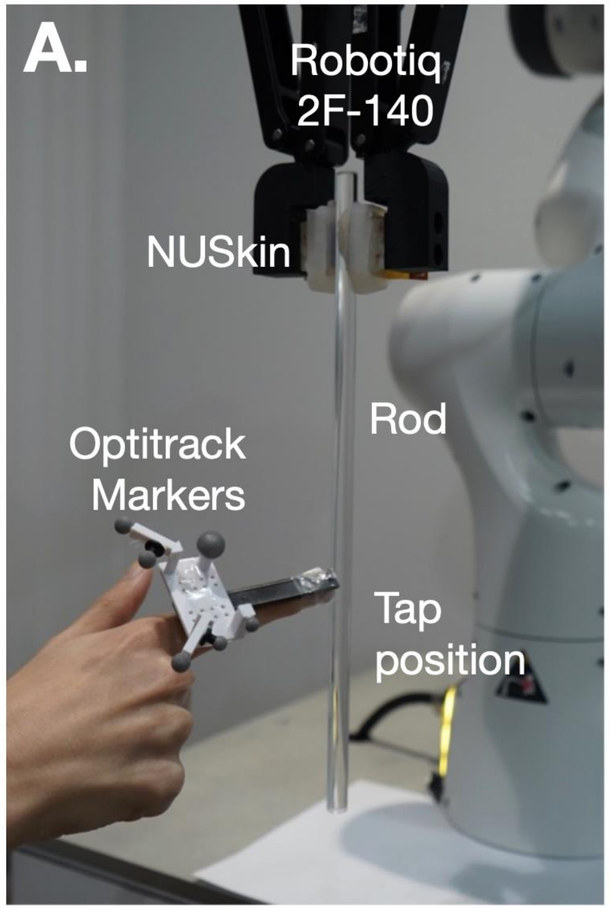


Food Identification



Sensory Extension Tasks

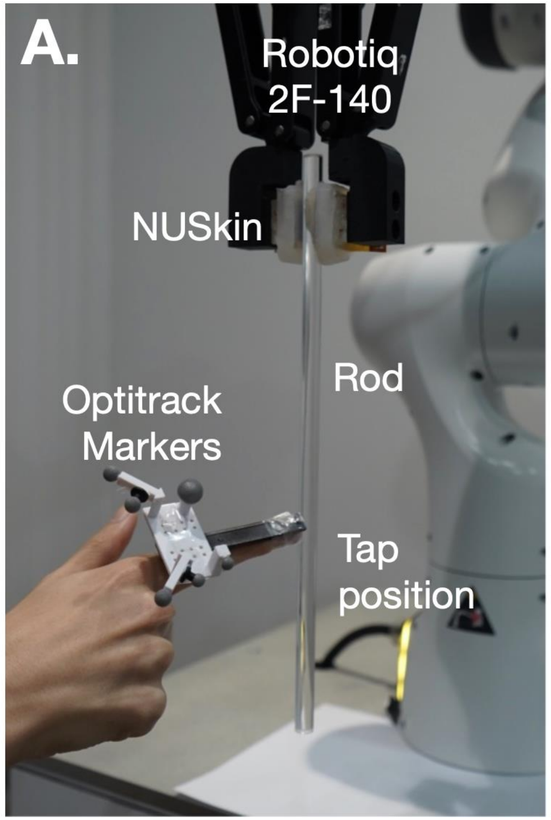
Tap Localization



Grasp Stability

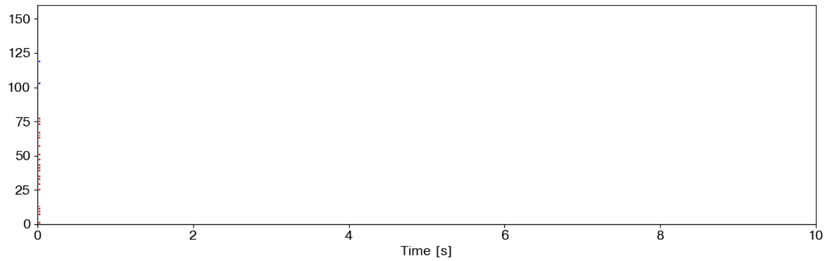
Food Identification

Tap Localization

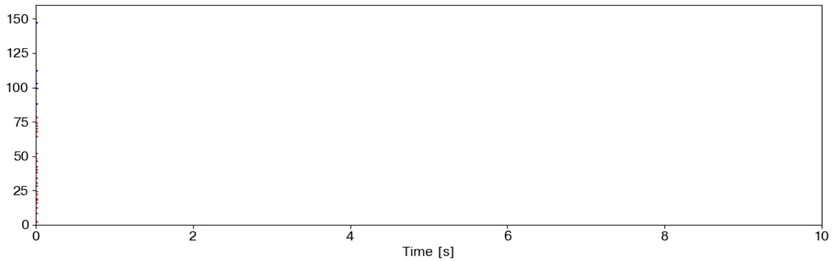


Total - 1000 samples
10% testing set
4-fold (20 times, except 5 for RNN)

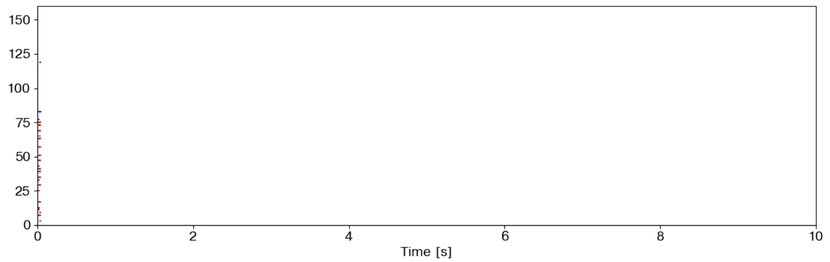
Tap Localization



20 cm



30 cm



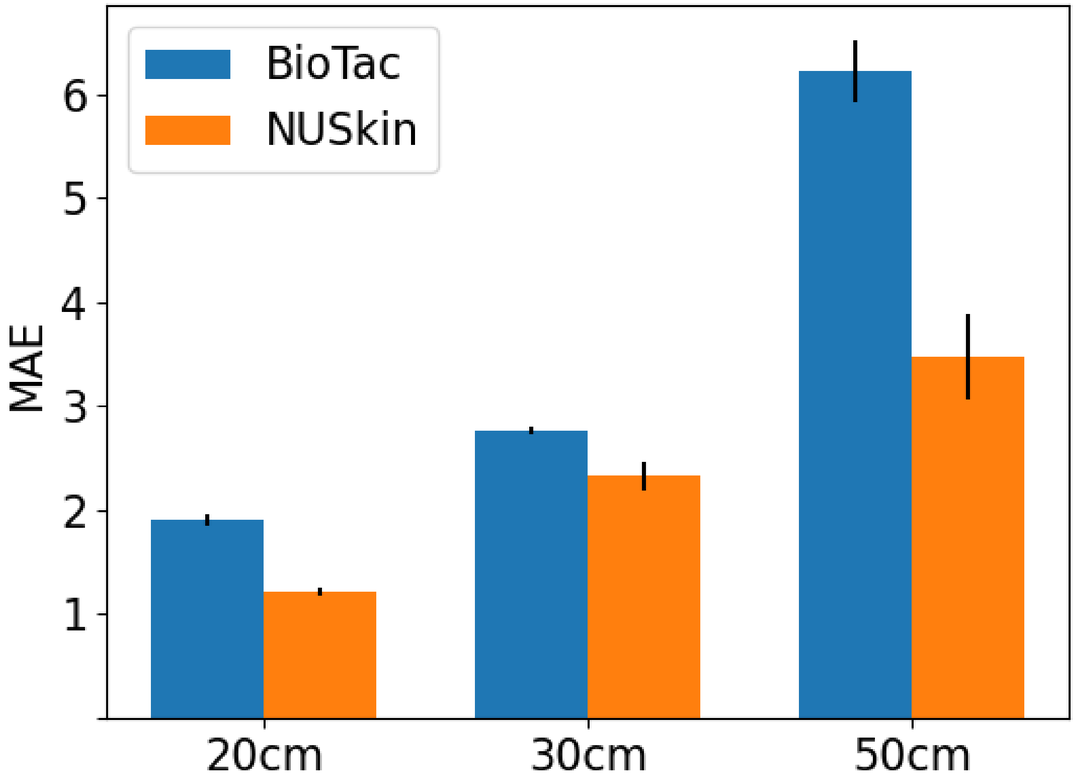
50 cm

Can the robot localize contacts?

		20cm		30cm		50cm	
		BioTAC (PAC)	NUSkin	BioTAC (PAC)	NUSkin	BioTAC (PAC)	NUSkin
SVR Linear	Baseline	2.5492 ± 0.1873	1.7102 ± 0.0913	3.8219 ± 0.2584	3.2682 ± 0.1861	6.3491 ± 0.5526	4.2323 ± 0.4525
	FFT	2.2397 ± 0.0821	1.3864 ± 0.0448	3.4202 ± 0.2153	2.7135 ± 0.1811	6.5452 ± 0.3566	3.8361 ± 0.5234
	Autoencoder	2.6015 ± 0.2132	2.1976 ± 0.1058	4.3844 ± 0.1394	4.0754 ± 0.3331	7.4146 ± 0.4647	6.0886 ± 0.4546
	Kernel		1.5260 ± 0.1176		2.7310 ± 0.0862		3.8520 ± 0.4105
SVR RBF	Baseline	2.0729 ± 0.1506	1.5411 ± 0.1029	3.0808 ± 0.1454	2.8592 ± 0.1871	5.2913 ± 0.4026	3.5130 ± 0.4029
	FFT	1.9021 ± 0.0516	1.2053 ± 0.0376	2.7636 ± 0.0370	2.3250 ± 0.1395	6.2178 ± 0.3066	3.4561 ± 0.4067
	Autoencoder	2.3188 ± 0.1957	1.8579 ± 0.1395	3.5110 ± 0.2027	3.9692 ± 0.3306	6.5044 ± 0.4685	4.7812 ± 0.3819
	Kernel		1.4472 ± 0.1299		2.6060 ± 0.1661		3.4290 ± 0.3368
MLP	Baseline	2.3579 ± 0.2896	1.9006 ± 0.1239	3.8654 ± 0.5083	2.9053 ± 0.1040	5.1097 ± 0.5556	3.8222 ± 0.5322
	FFT	1.7079 ± 0.0278	1.6415 ± 0.3577	2.7636 ± 0.0370	2.3250 ± 0.1395	5.2028 ± 0.6282	4.1149 ± 0.6749
	Autoencoder	2.4047 ± 0.2135	2.0130 ± 0.1565	4.2544 ± 0.3960	4.1346 ± 0.3691	6.5187 ± 0.5216	5.5296 ± 0.6103
	Kernel		1.3964 ± 0.1488		2.0273 ± 0.1546		3.4227 ± 0.3272
RNN + MLP	Baseline	2.2773 ± 0.4501	**0.9288 ± 0.2015**	4.7522 ± 1.1578	**1.2339 ± 0.1775**	4.7450 ± 0.8914	3.2920 ± 1.2359
	Kernel		1.3320 ± 0.2319		1.7354 ± 0.2097		**3.0750 ± 0.4830**

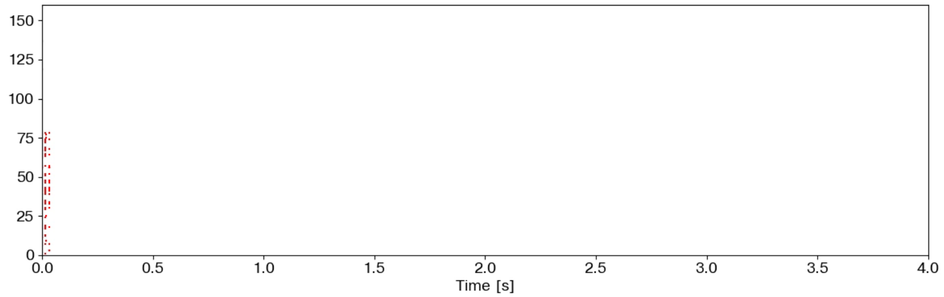
Can the robot localize contacts?

Yes.

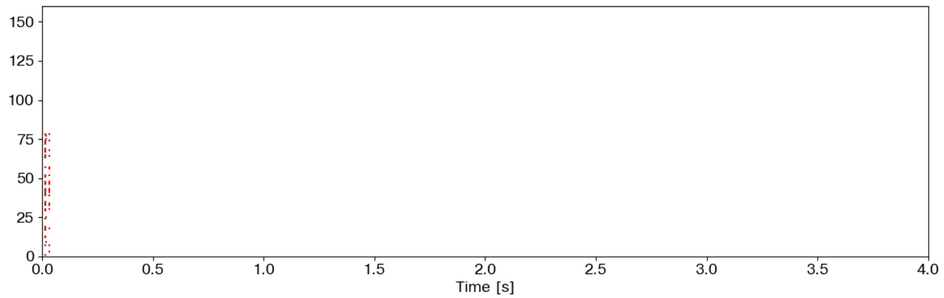


Lowest Errors ≈ 1cm on 20cm rod

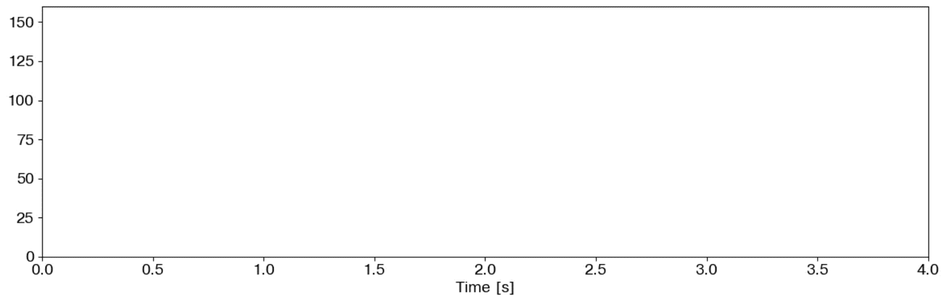
How fast do we need to sample?



4000 Hz



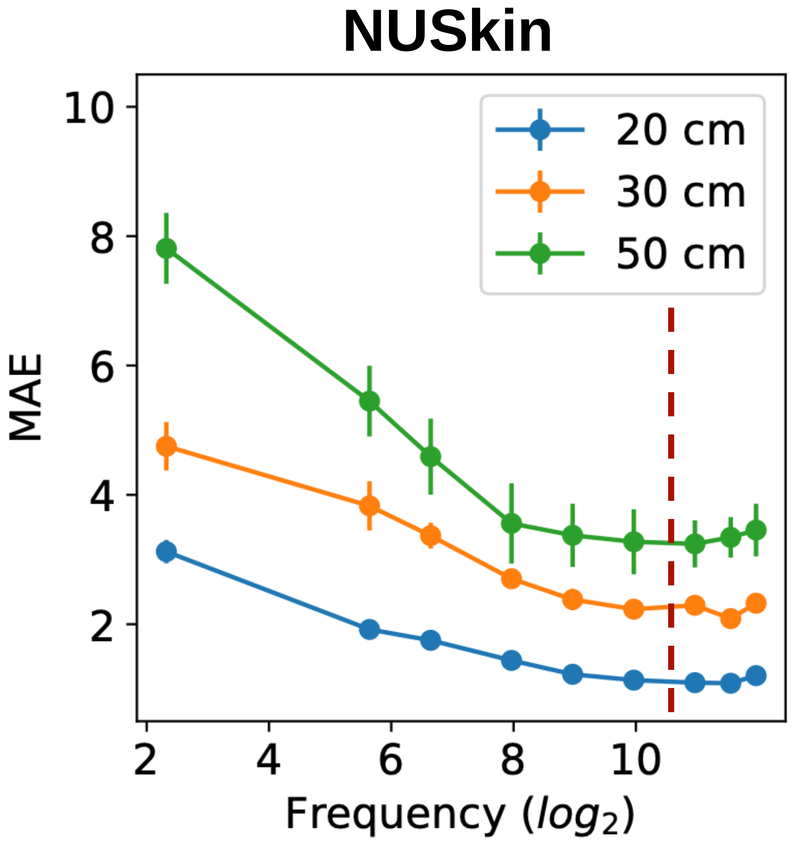
100 Hz

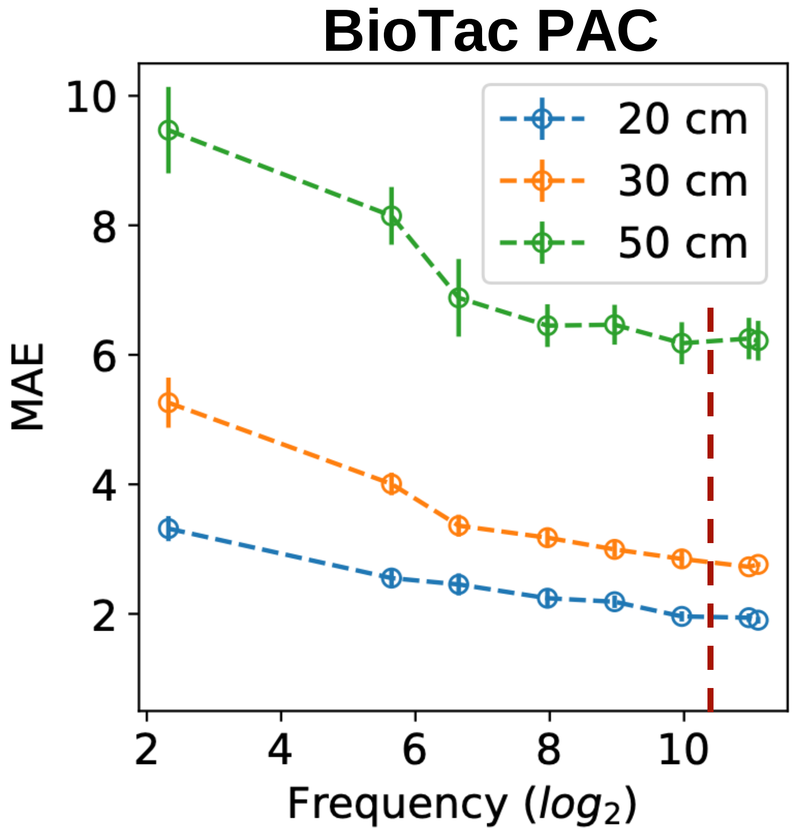


5 Hz

How fast do we need to sample?

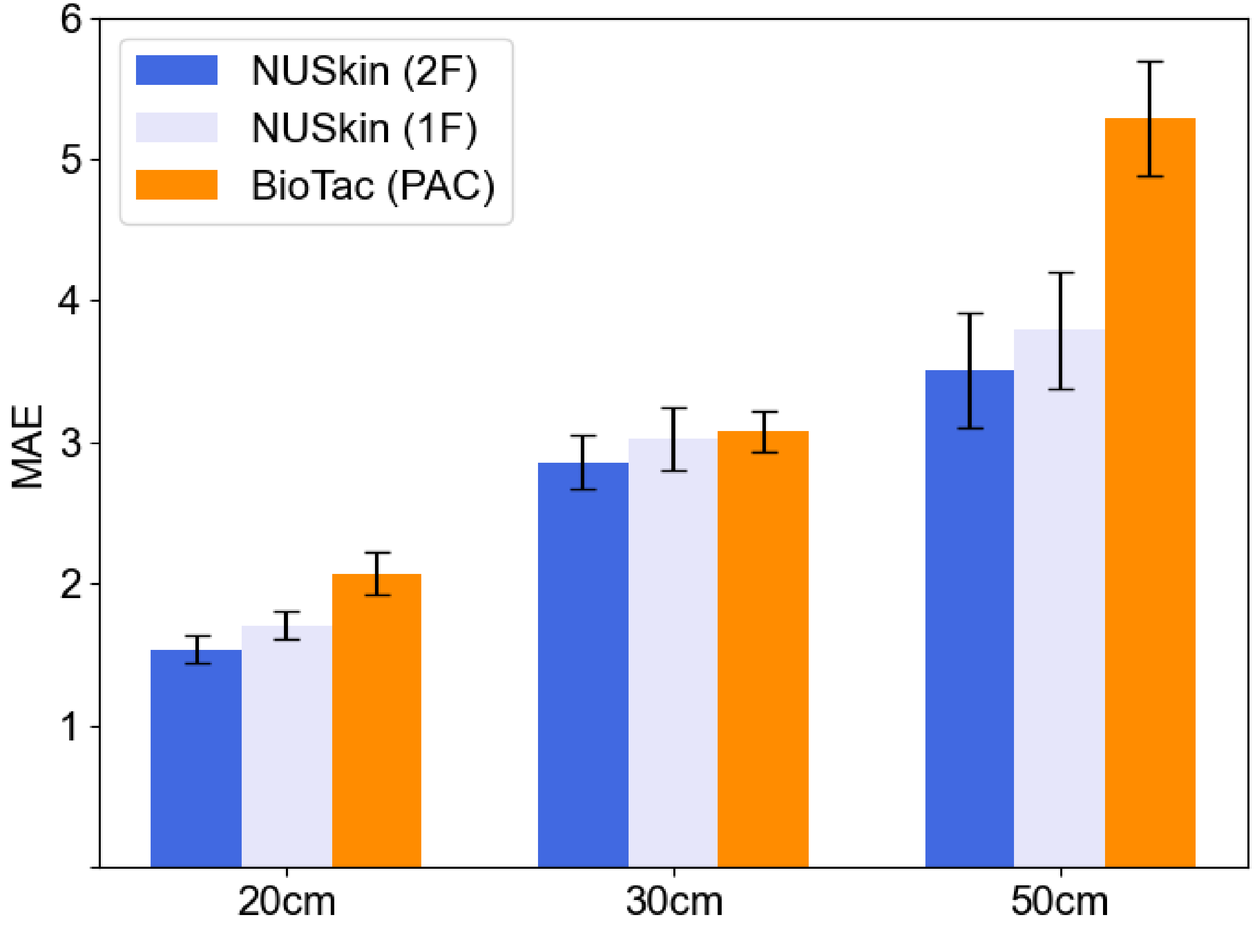
≈ 2-3 kHz





Do multiple spatially-distributed taxels help?

Yes.



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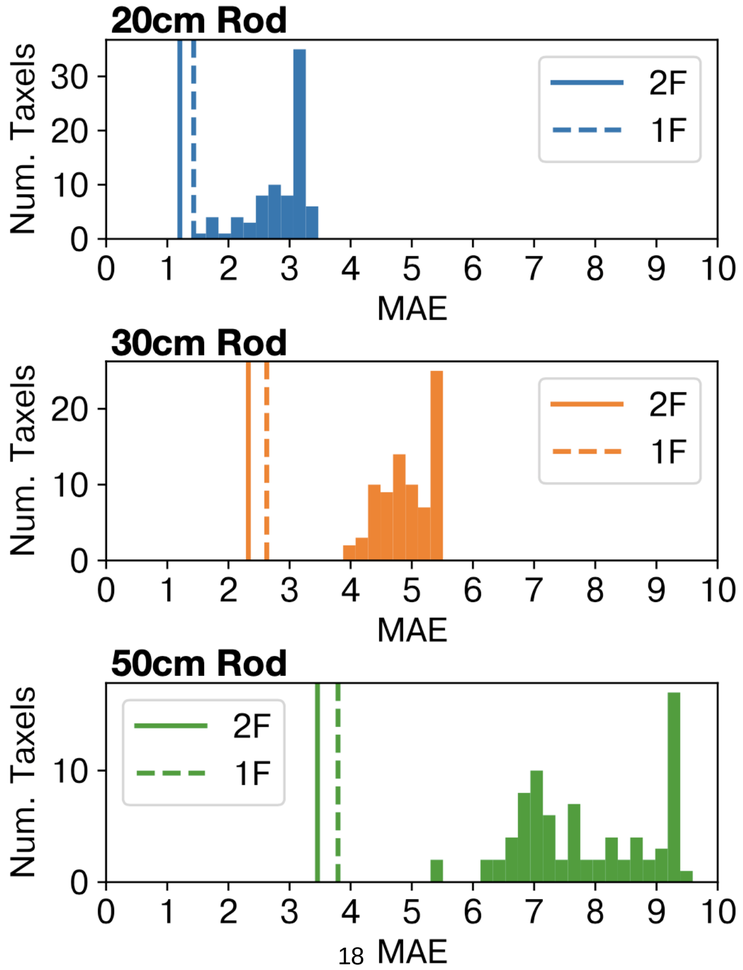
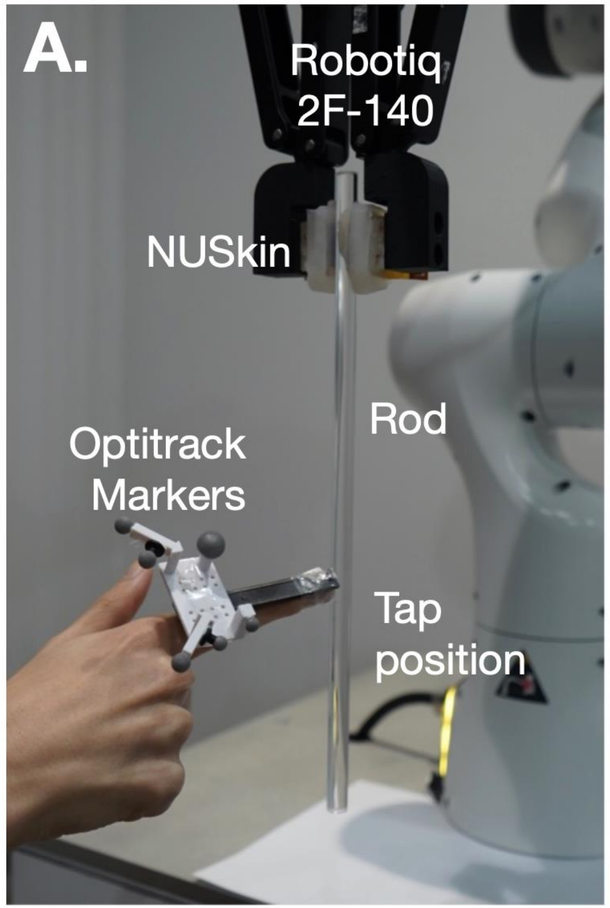


Sensory Extension Tasks

Tap Localization



Grasp Stability

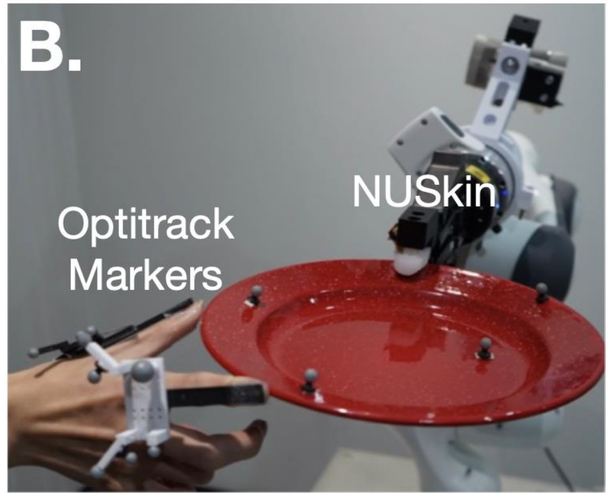
Food Identification

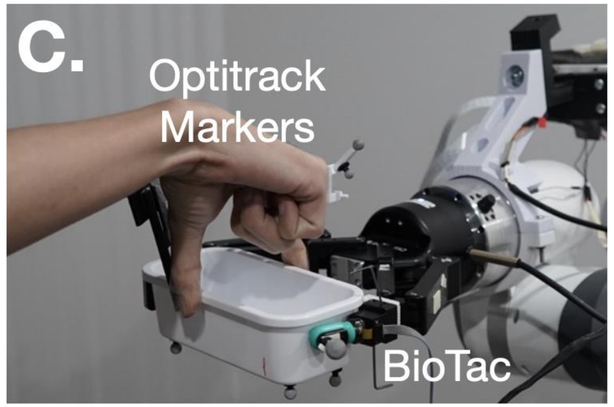
Sensory Extension Tasks

Tap Localization

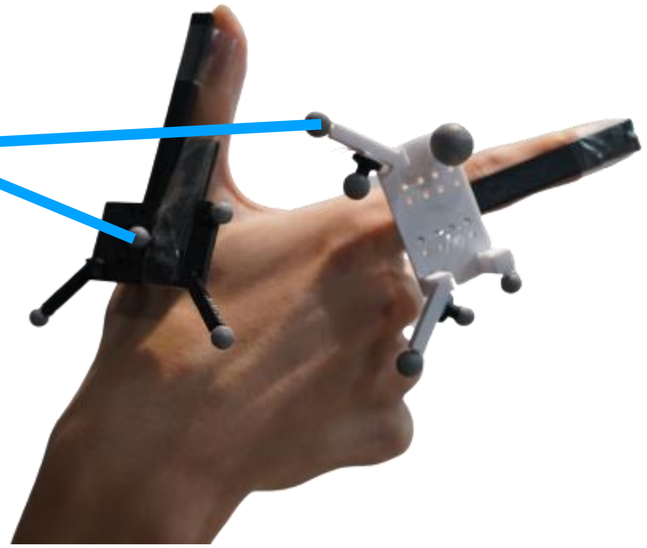
Grasp Stability

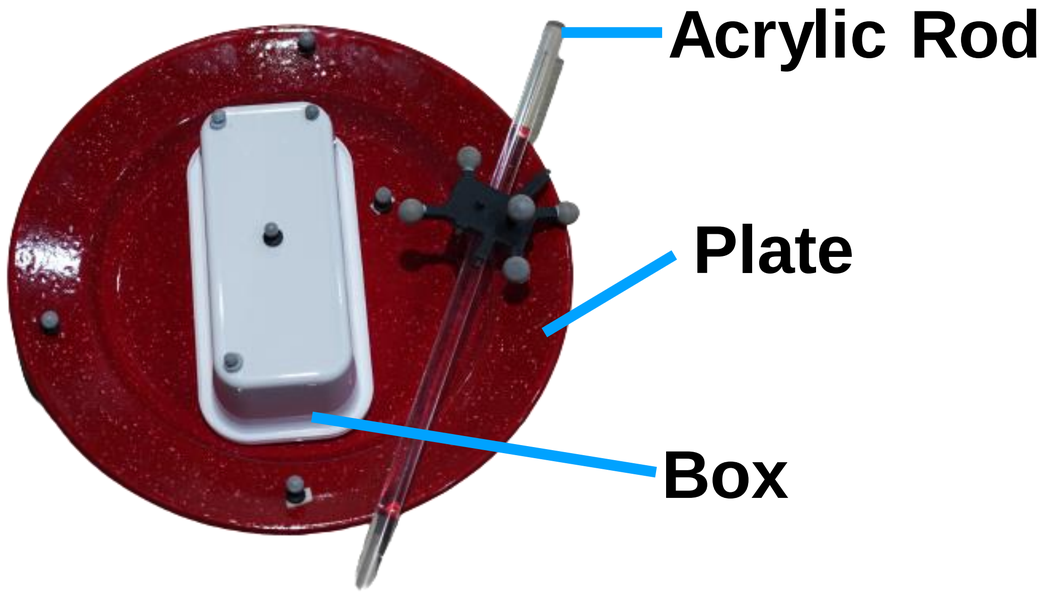
Food Identification





Grasp Stability Prediction

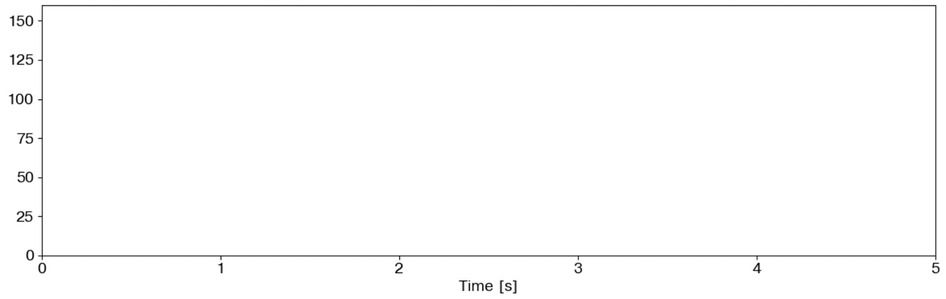




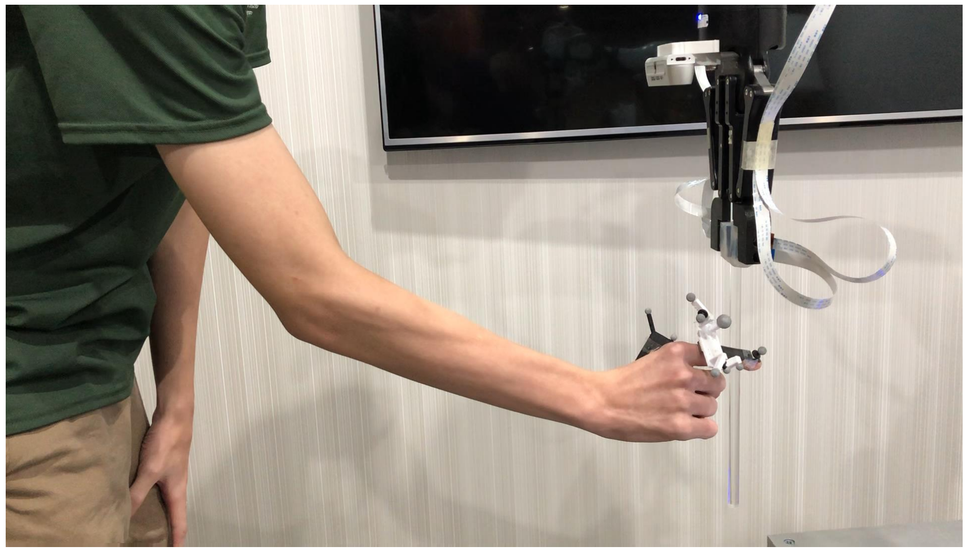
3 objects, 50 positive & negative grasps
Total - 300 samples

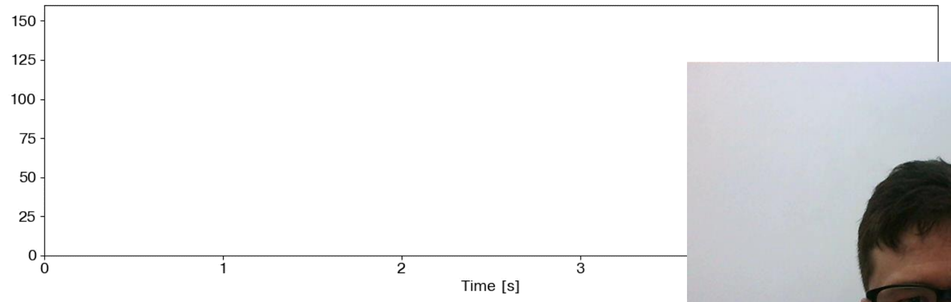
Grasp Stability Prediction

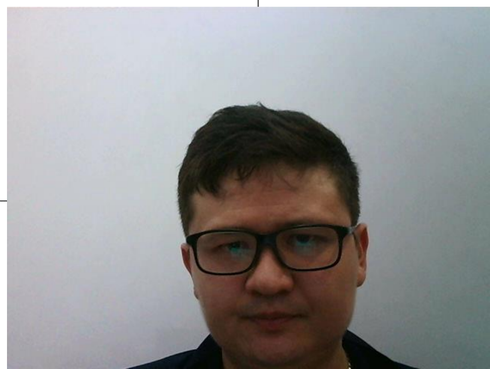
Positive

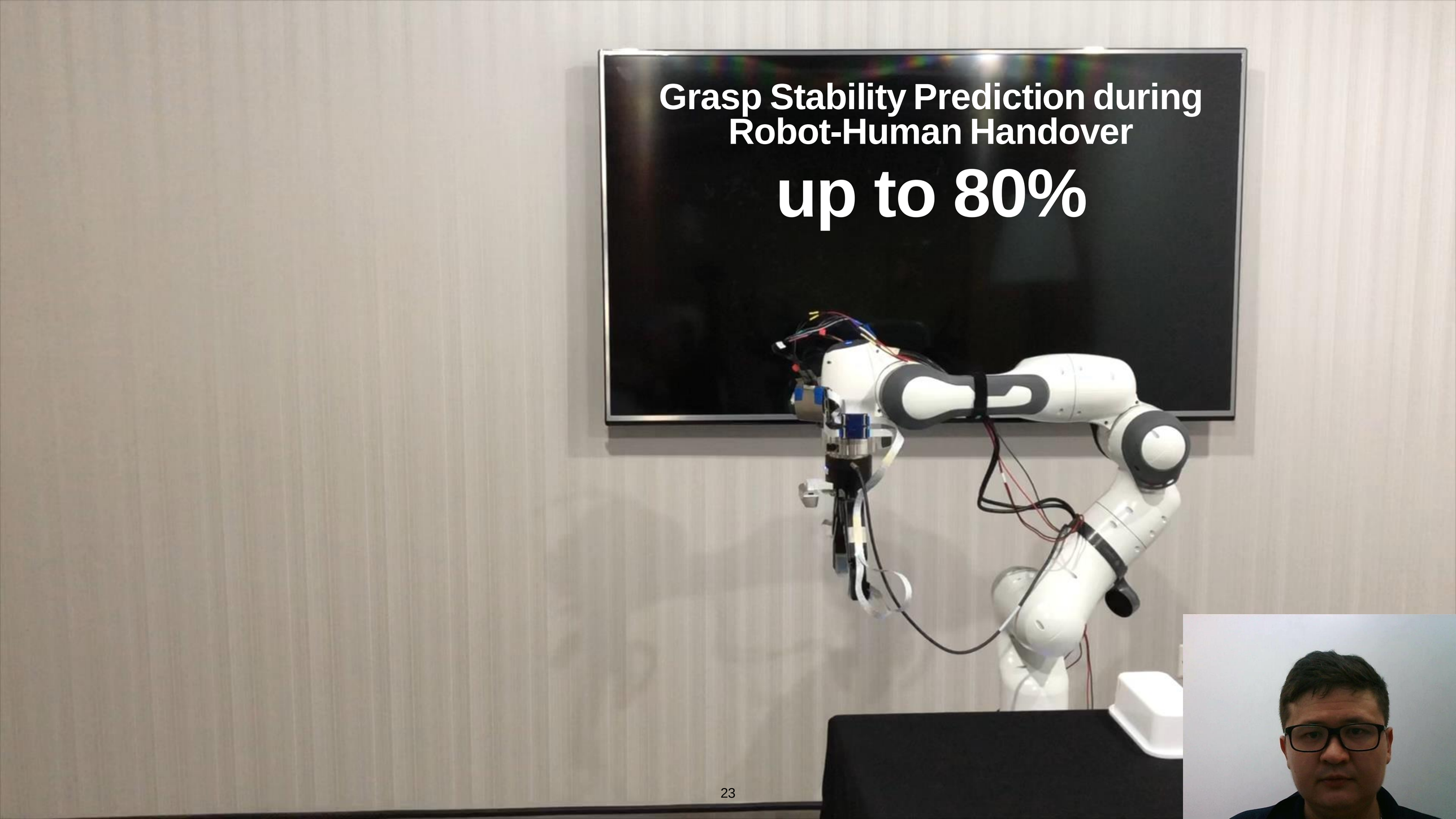


Negative



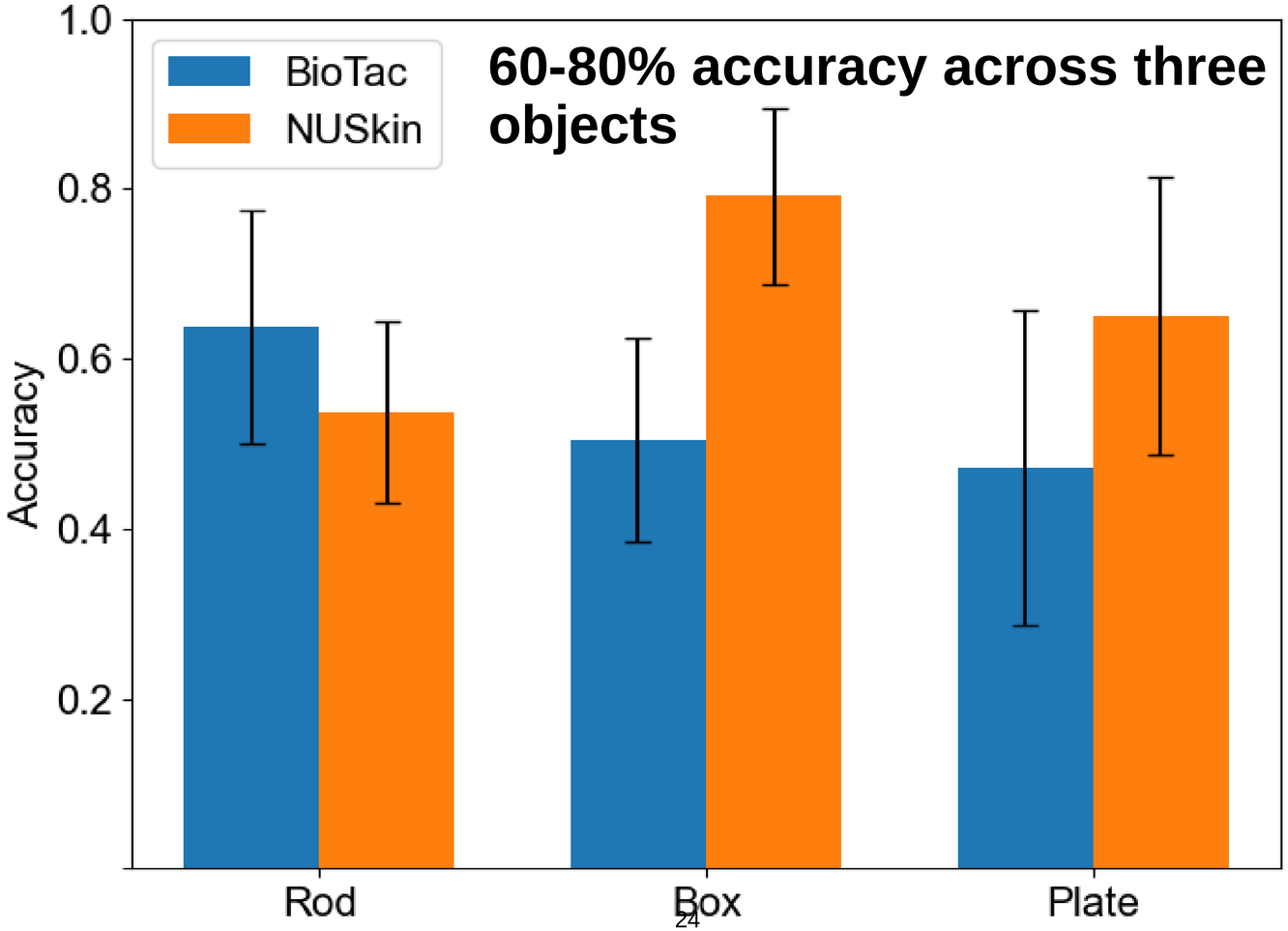





Grasp Stability Prediction during
Robot-Human Handover
up to 80%

Can we predict grasp stability?

Yes.

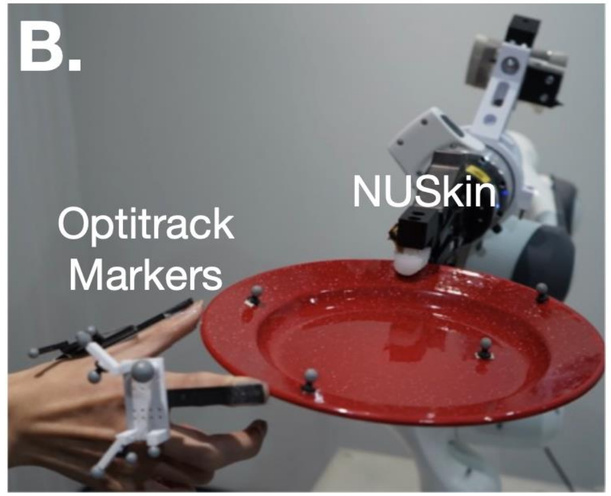


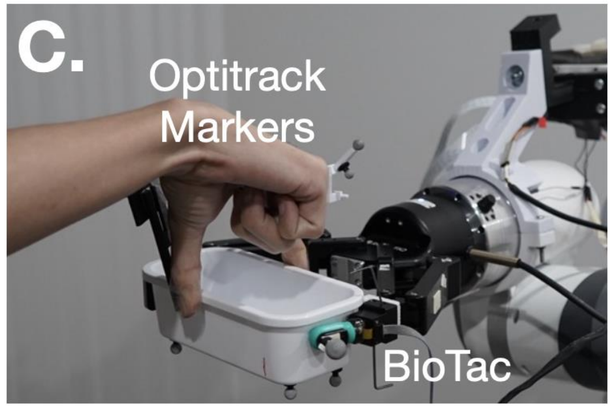
Sensory Extension Tasks

Tap Localization

Grasp Stability

Food Identification





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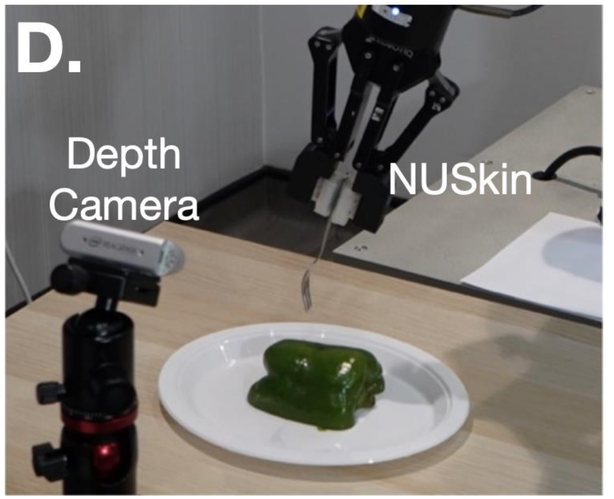
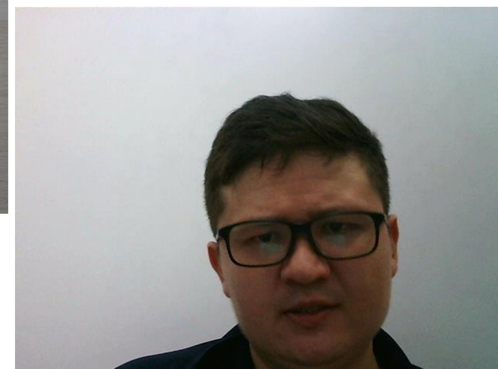
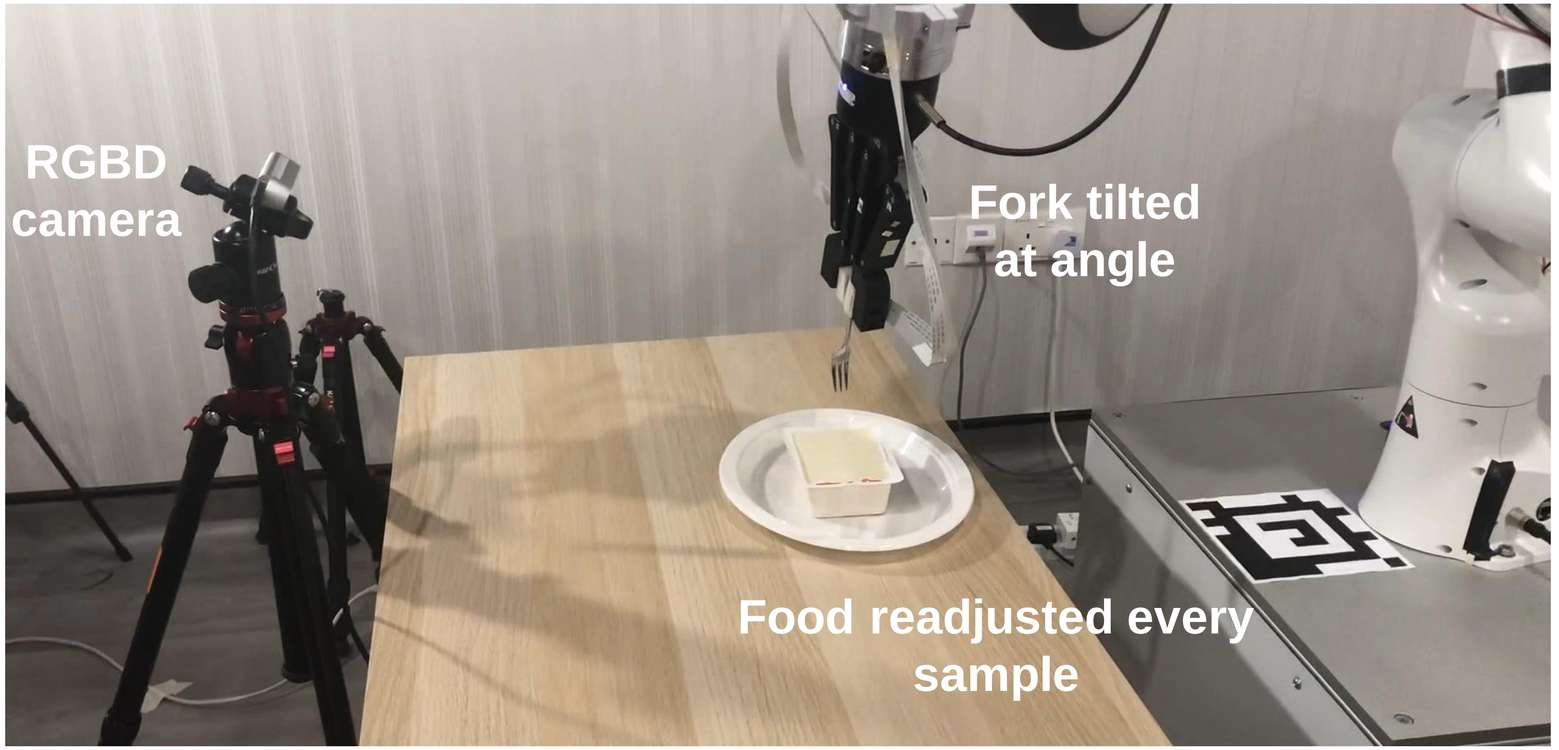




Food Classification



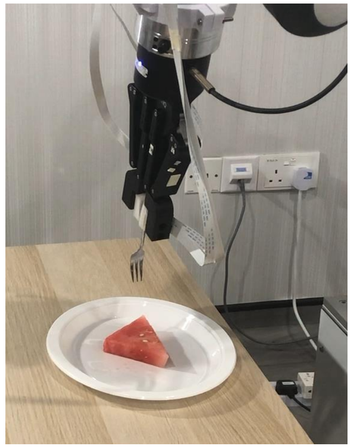
7 Food Classes

Empty

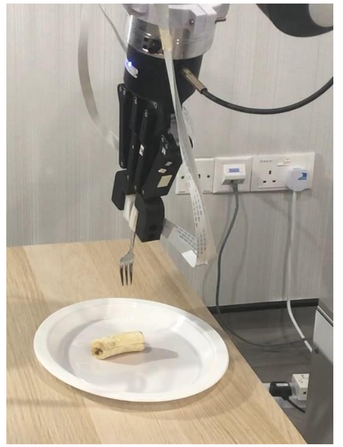
Water

Tofu

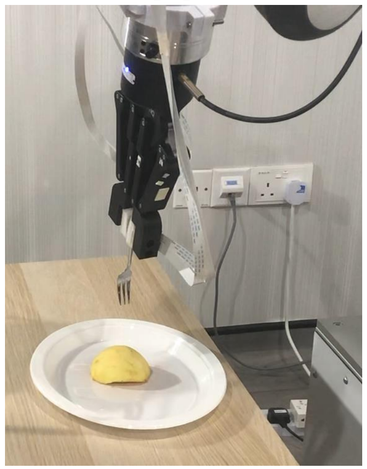
Watermelon



Banana

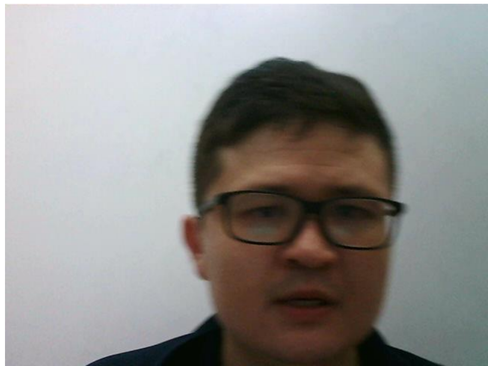


Apple



Pepper

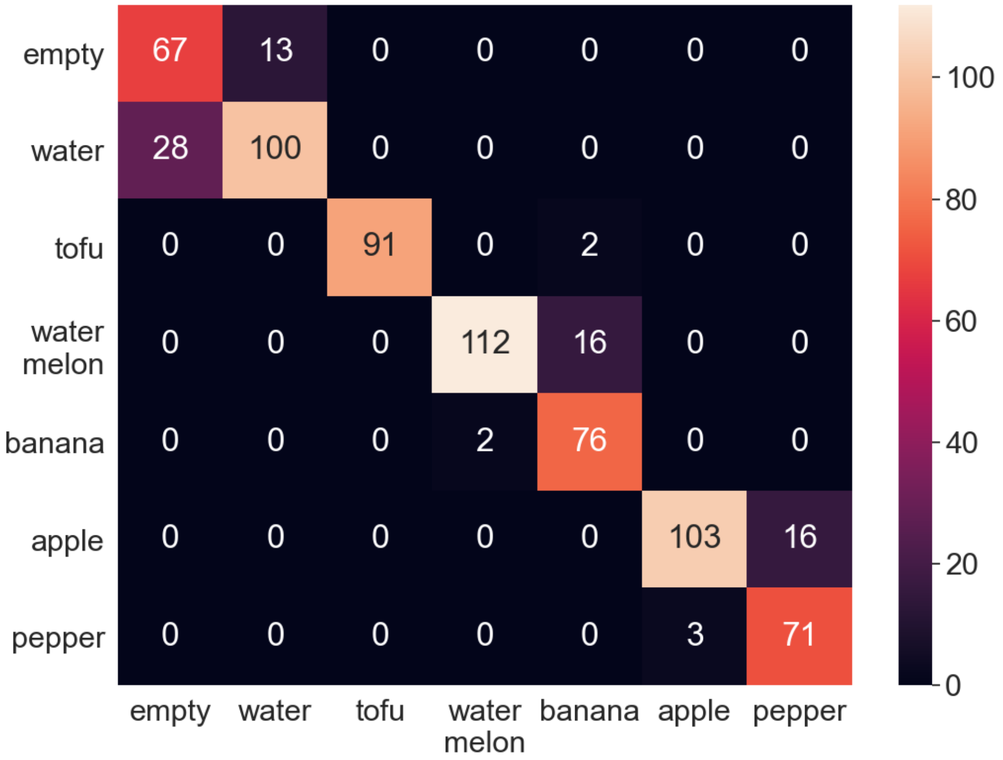
Total 50*7 = 350 samples



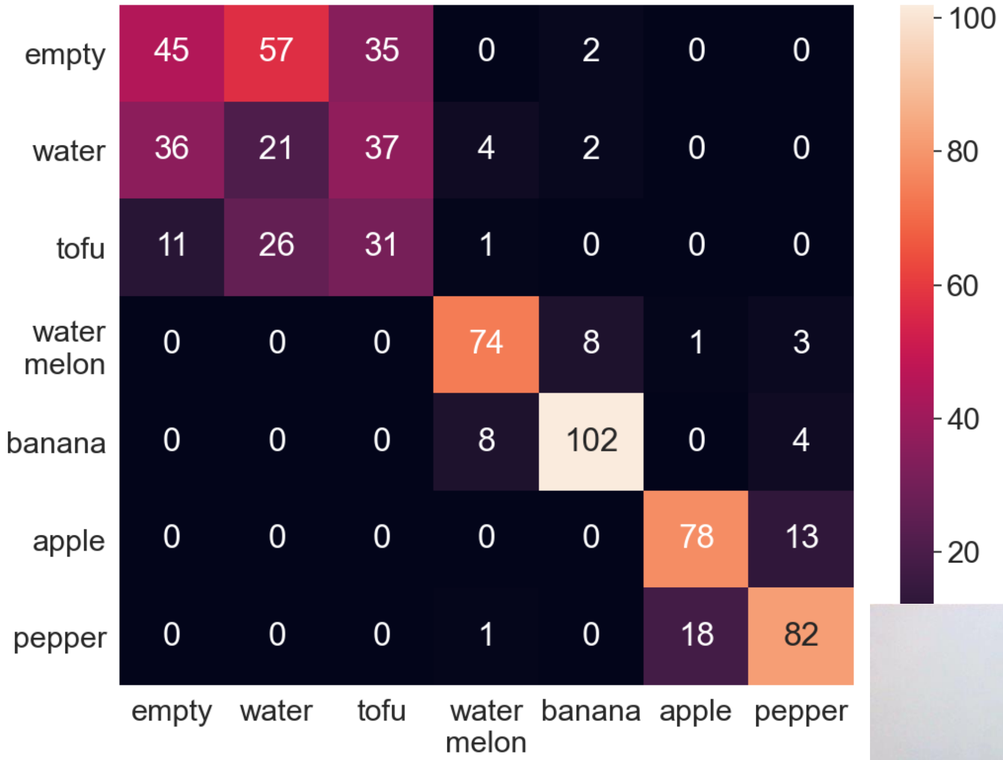
Can we classify different food types?

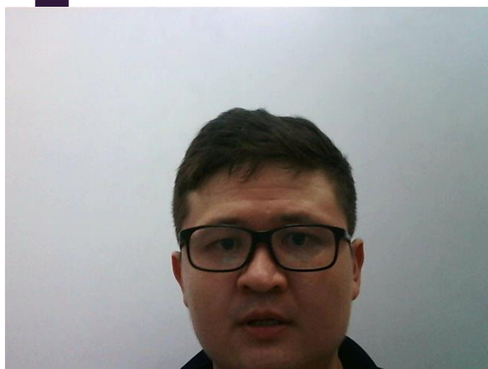
Yes.

NUSkin



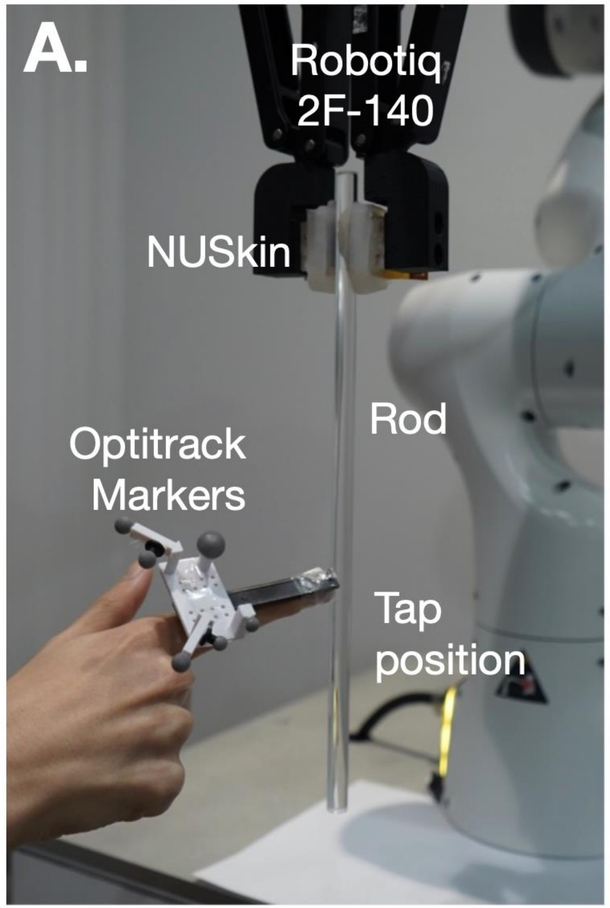
BioTac PAC



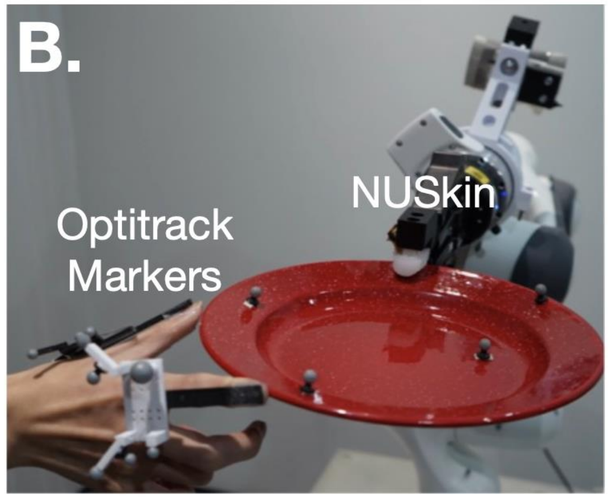


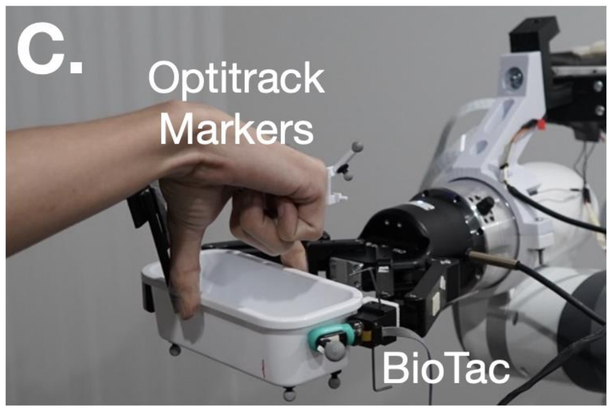
Sensory Extension Tasks

Tap Localization

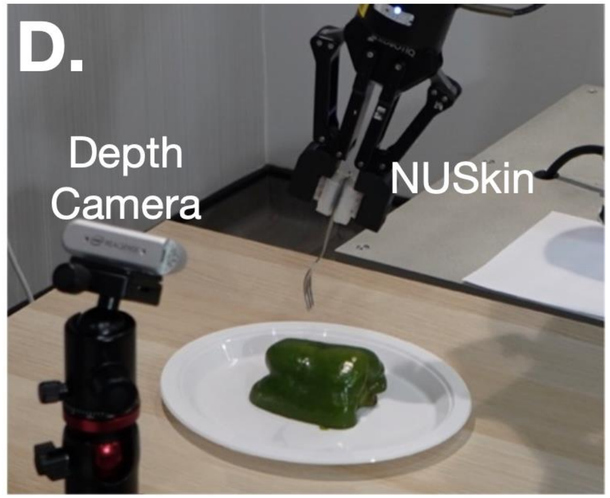


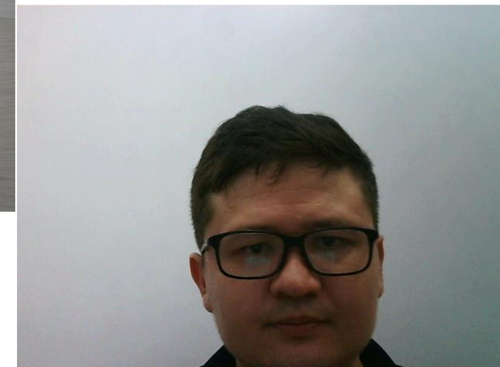
Grasp Stability





Food Identification



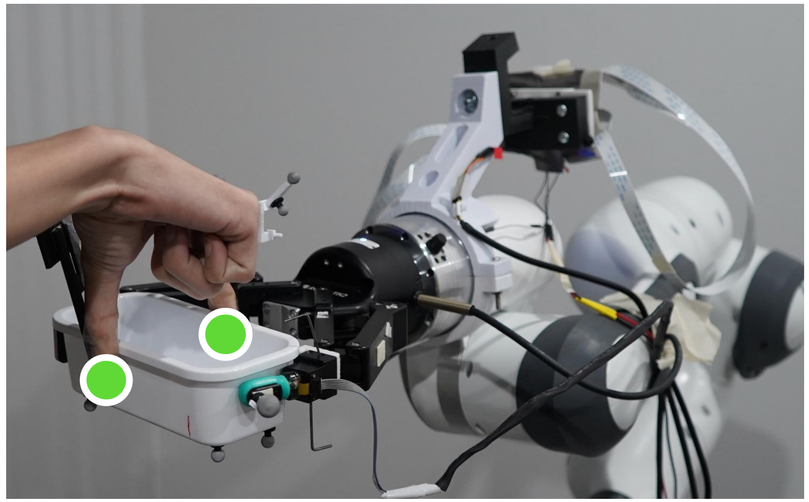


Summary of Findings

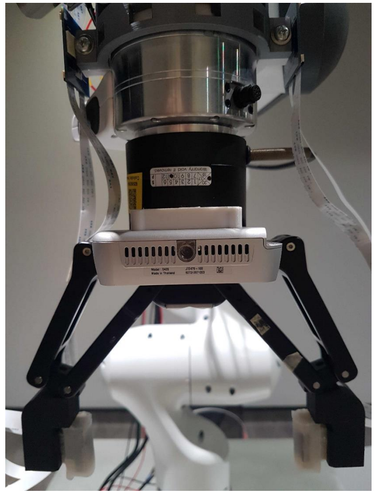
Can the robot **localize contacts**?	**Yes, lowest errors ~1.0cm**
How **fast** do we need to **sample**?	**2-3 kHz**
Do we need **multiple taxels**?	**Yes, using all 80 taxels led to higher accuracy**
Can we **identify stable grasps** during robot-human handover?	**Yes, 60-80% accuracy**
Can we **identify foods** using a regular fork?	**Yes, 90% accuracy**

Future Work

Non-rigid and multiple link tools



Localization on 3D surfaces



Multi-modal perception

Extended Tactile Perception:

Vibration Sensing through Tools and Grasped Objects

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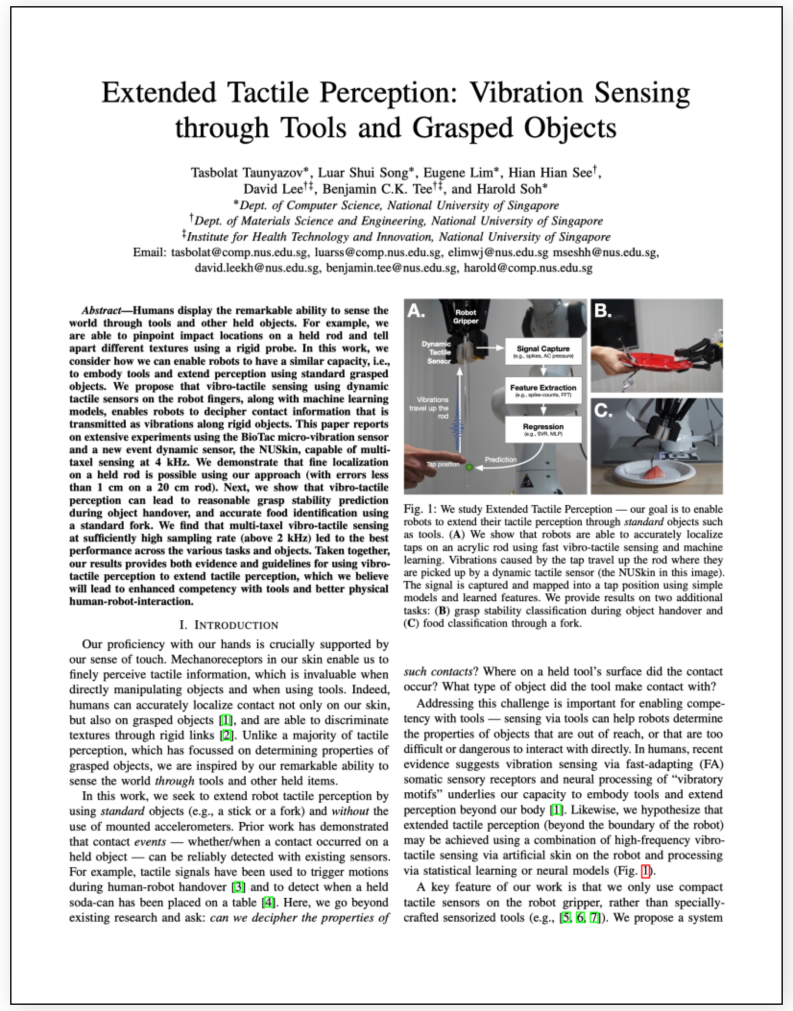

Extended Tactile Perception: Vibration Sensing through Tools and Grasped Objects

Paper ID: #1188

https://arxiv.org/abs/2106.00489

https://github.com/clear-nus/ext-sense

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