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ROBOTICS SCIENCE AND SYSTEMS

Event-Driven Visual-Tactile Sensing and Learning for Robots

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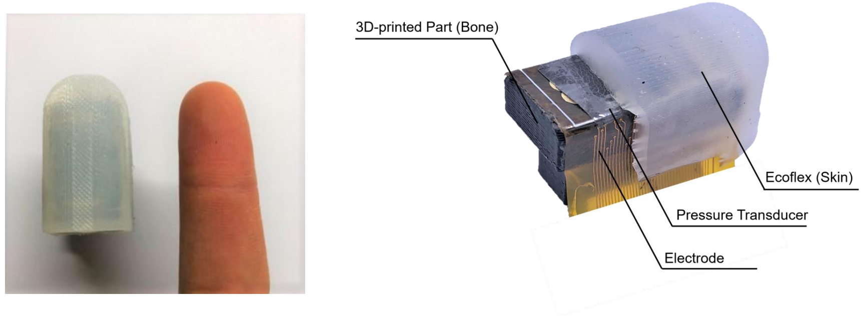
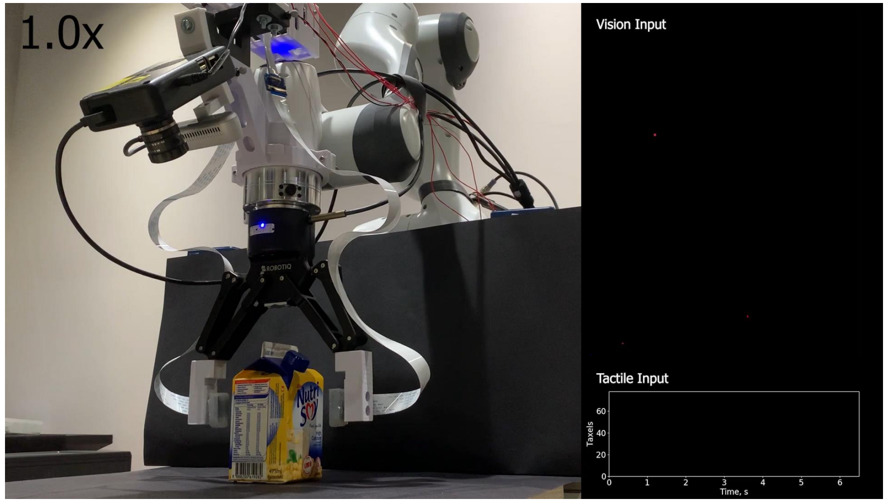
Event-Driven Visual-Tactile Sensing and Learning for Robots

1



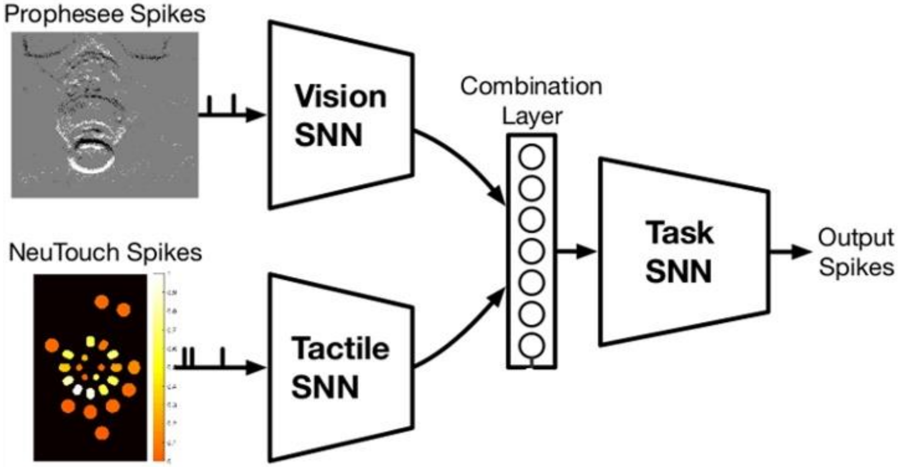
Event-based tactile sensor with graphene-based piezoresistive transducer



VT-SNN is tested for two different robotic tasks:

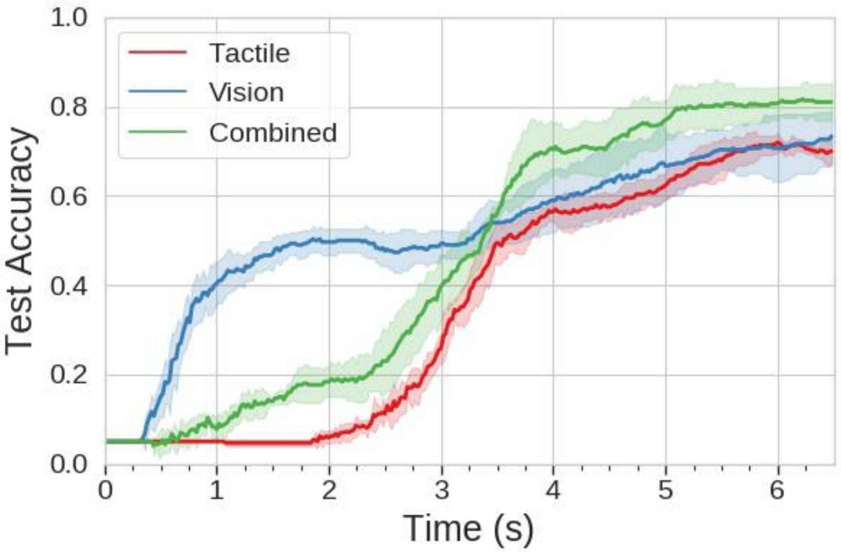
- Container and weight classification
- Rotational slip detection

2



Visual-Tactile Spiking Neural Network

$$L_\omega = \frac{1}{2}\sum_{n=0}^{N_o}\left(\sum_{t=0}^{T}\omega(t)s^n(t) - \sum_{t=0}^{T}\omega(t)\tilde{s}^n(t)\right)^2$$



We have achieved high early classification accuracy with proposed loss.

Multimodal datasets are publicly available at https://clear-nus.github.io/visuotactile/

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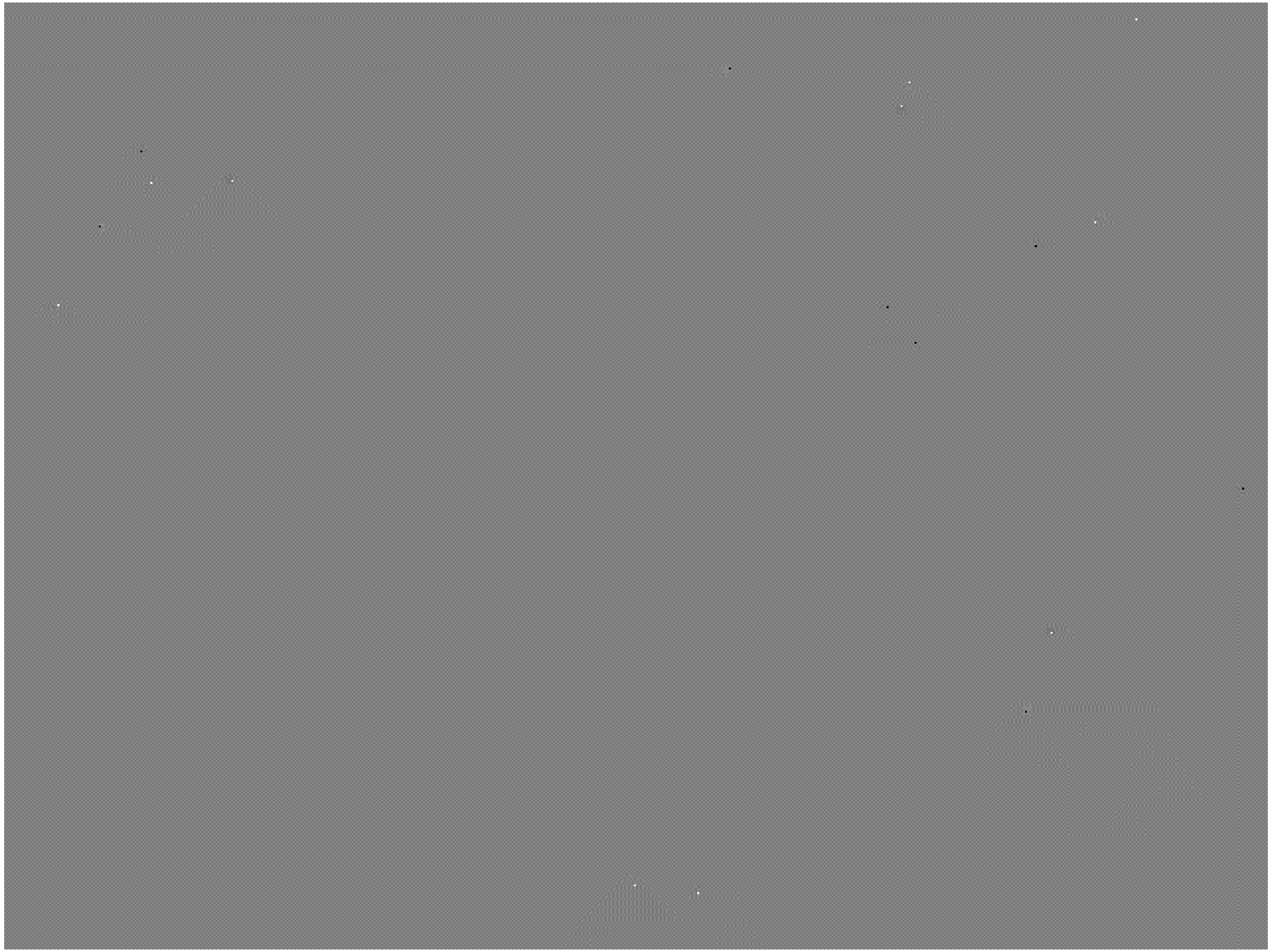
Event-Based Camera



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NeuTouch

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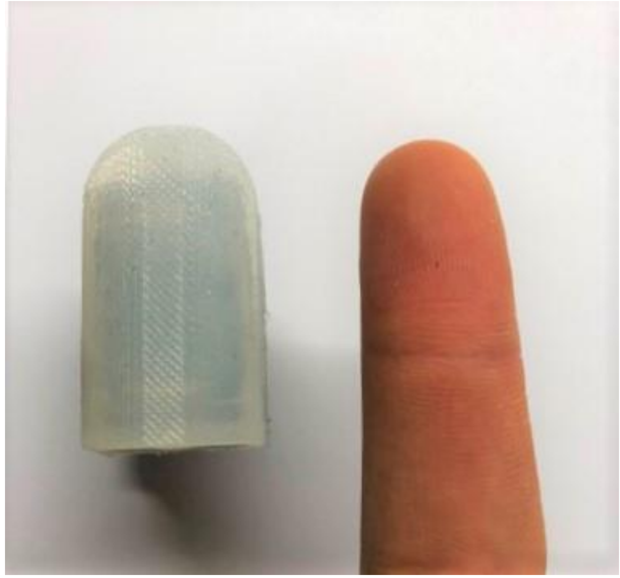

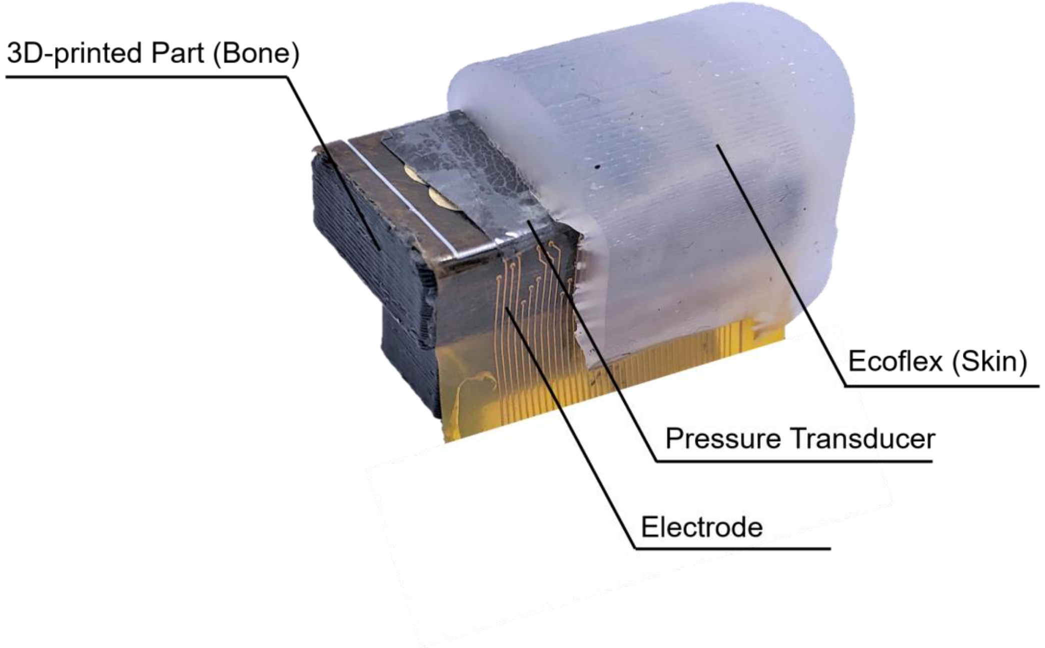

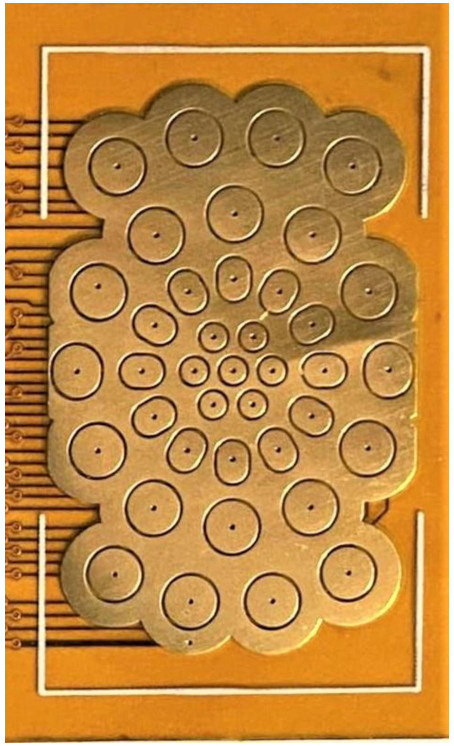

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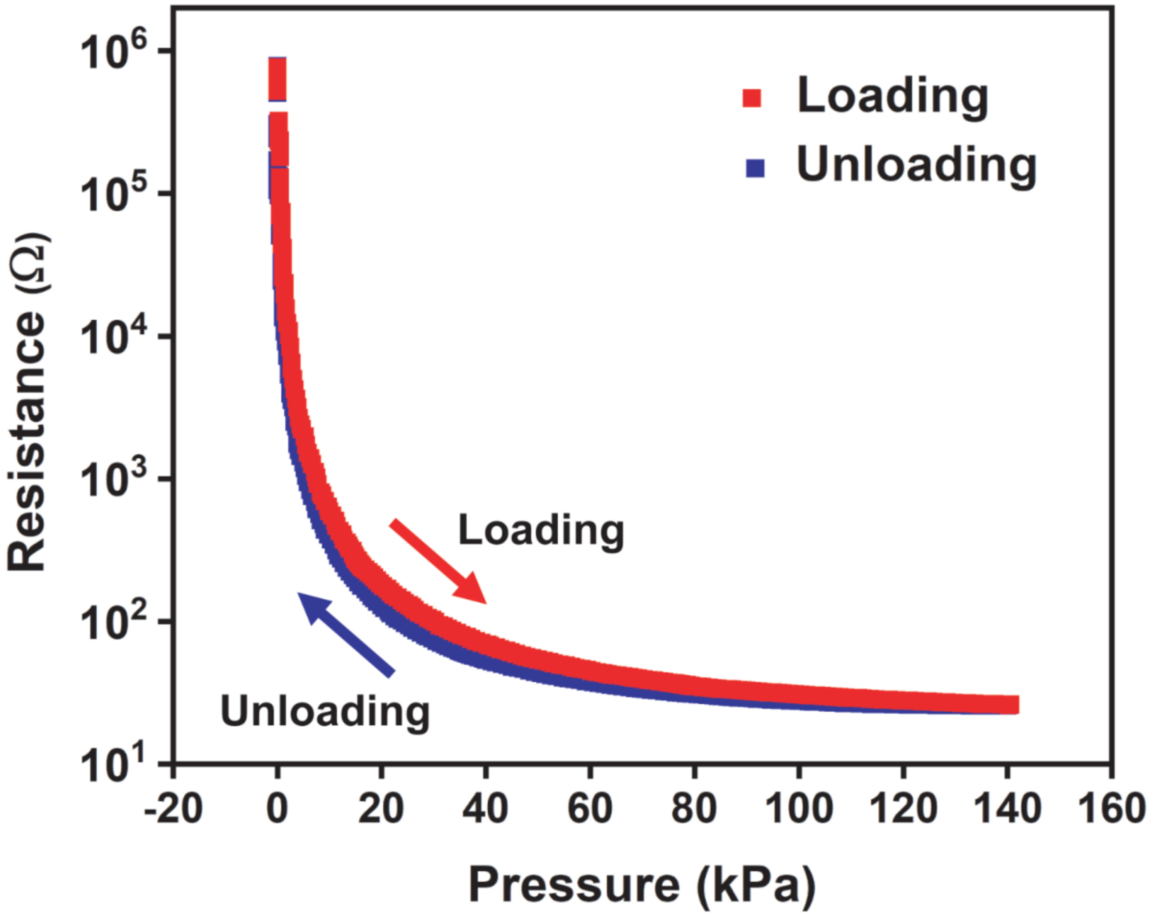
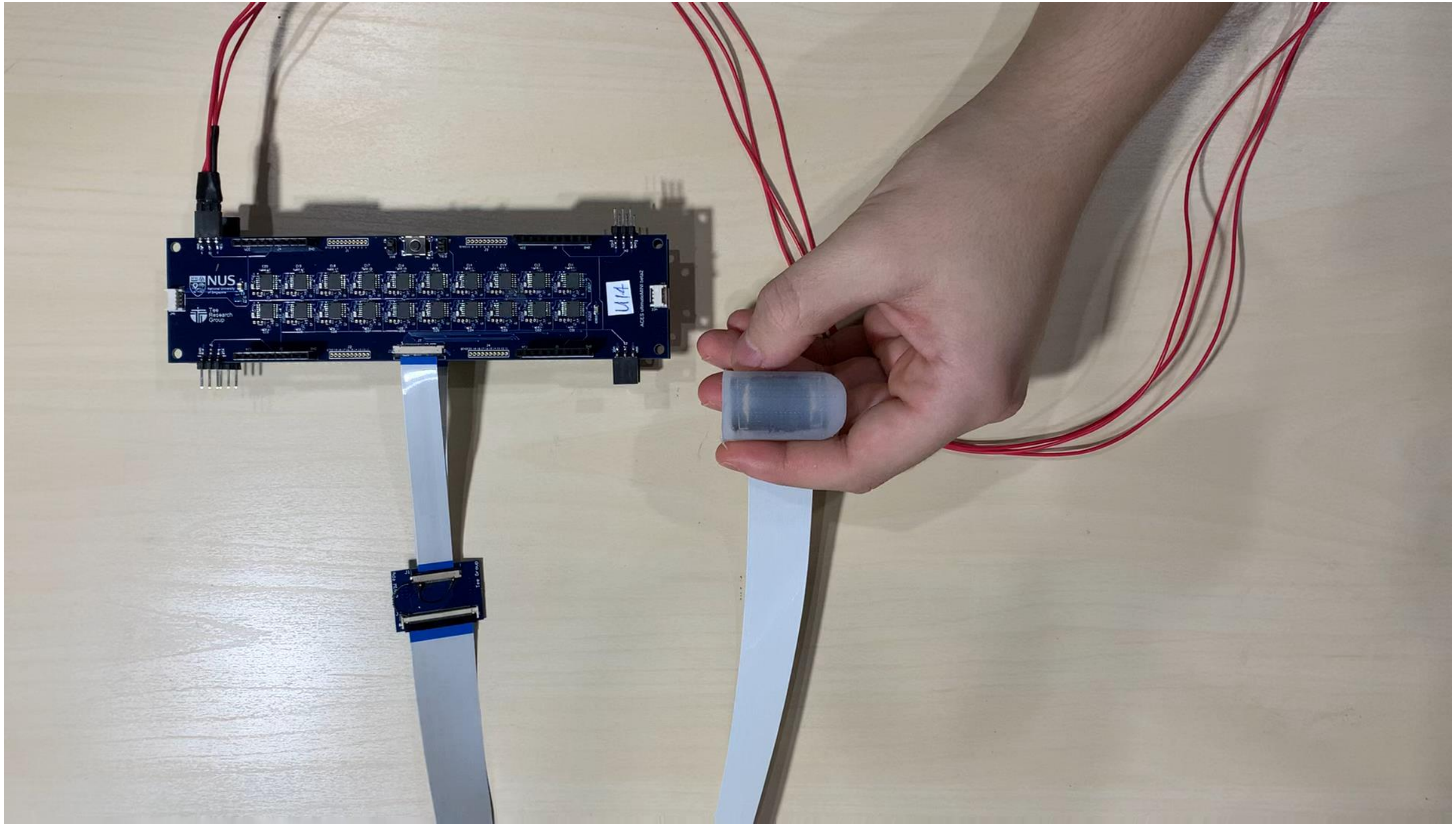
NeuTouch

Pressure response curve of the graphene-based pressure transducer.



NeuTouch (ACES)



Visual-Tactile Spiking Neural Network (VT-SNN)

Preprocessing:

Raw spike train

Threshold

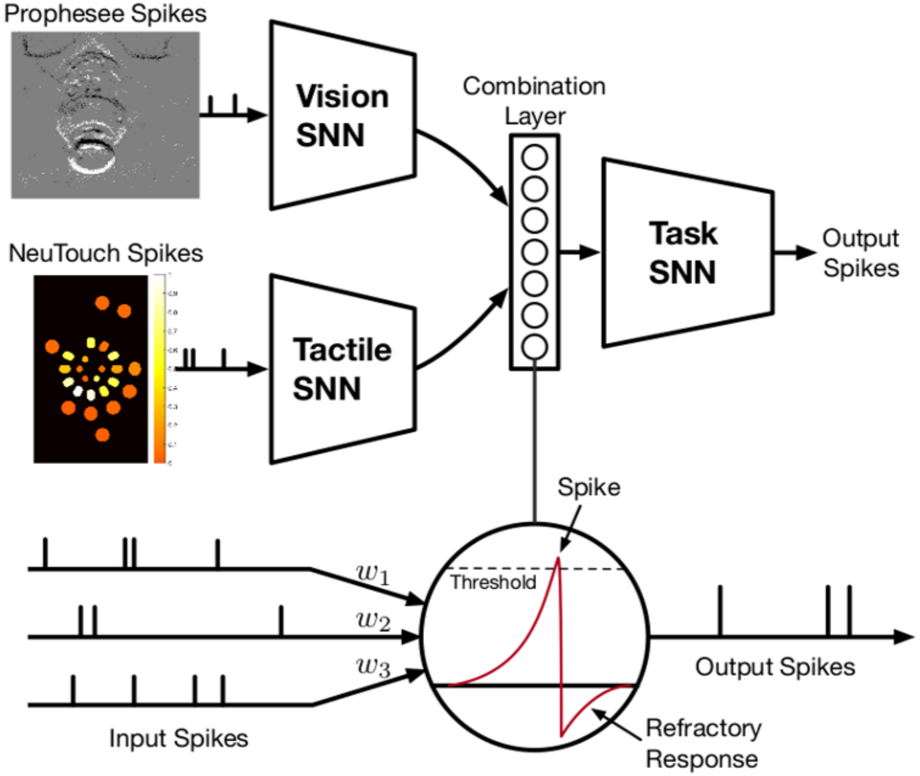
$$V_{\boxed{w}} = \begin{cases} 1 & \sum_{w} \boxed{S} \geq \boxed{S_{min}} \\ 0 & \text{otherwise} \end{cases}$$

Binning window length

Neuron Model (Spike Response Model):

$$u(t) = \sum w_i (\epsilon * s_i)(t) + (\nu * o)(t)$$

An output spike is generated whenever $u(t)$ reaches a predefined threshold ϑ.



Visual-Tactile Spiking Neural Network (VT-SNN)

Training:

Our VT-SNN is trained using SLAYER[1] framework.

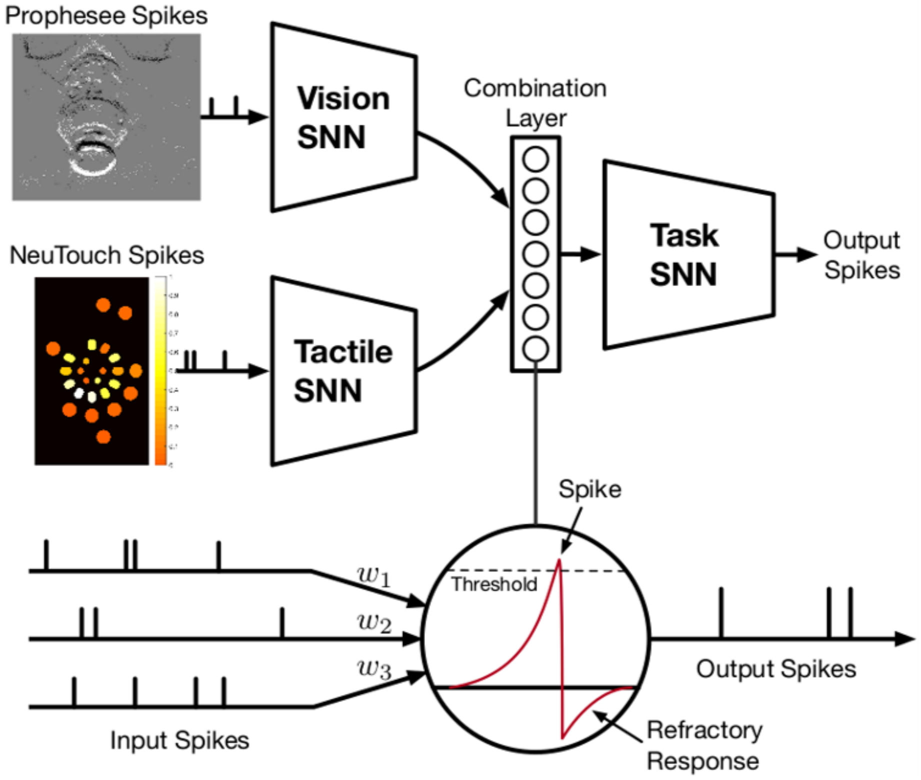
Losses

1. Standard Spike Count Loss:

$$L = \frac{1}{2}\sum_{n=0}^{N_o}\left(\underbrace{\sum_{t=0}^{T} s^n(t)}_{\text{Obtained counts}} - \underbrace{\sum_{t=0}^{T} \tilde{s}^n(t)}_{\text{Desired counts}}\right)^2$$

2. Proposed Weighted Spike Count Loss:

$$L_\omega = \frac{1}{2}\sum_{n=0}^{N_o}\left(\sum_{t=0}^{T} \omega(t) s^n(t) - \sum_{t=0}^{T} \omega(t) \tilde{s}^n(t)\right)^2$$



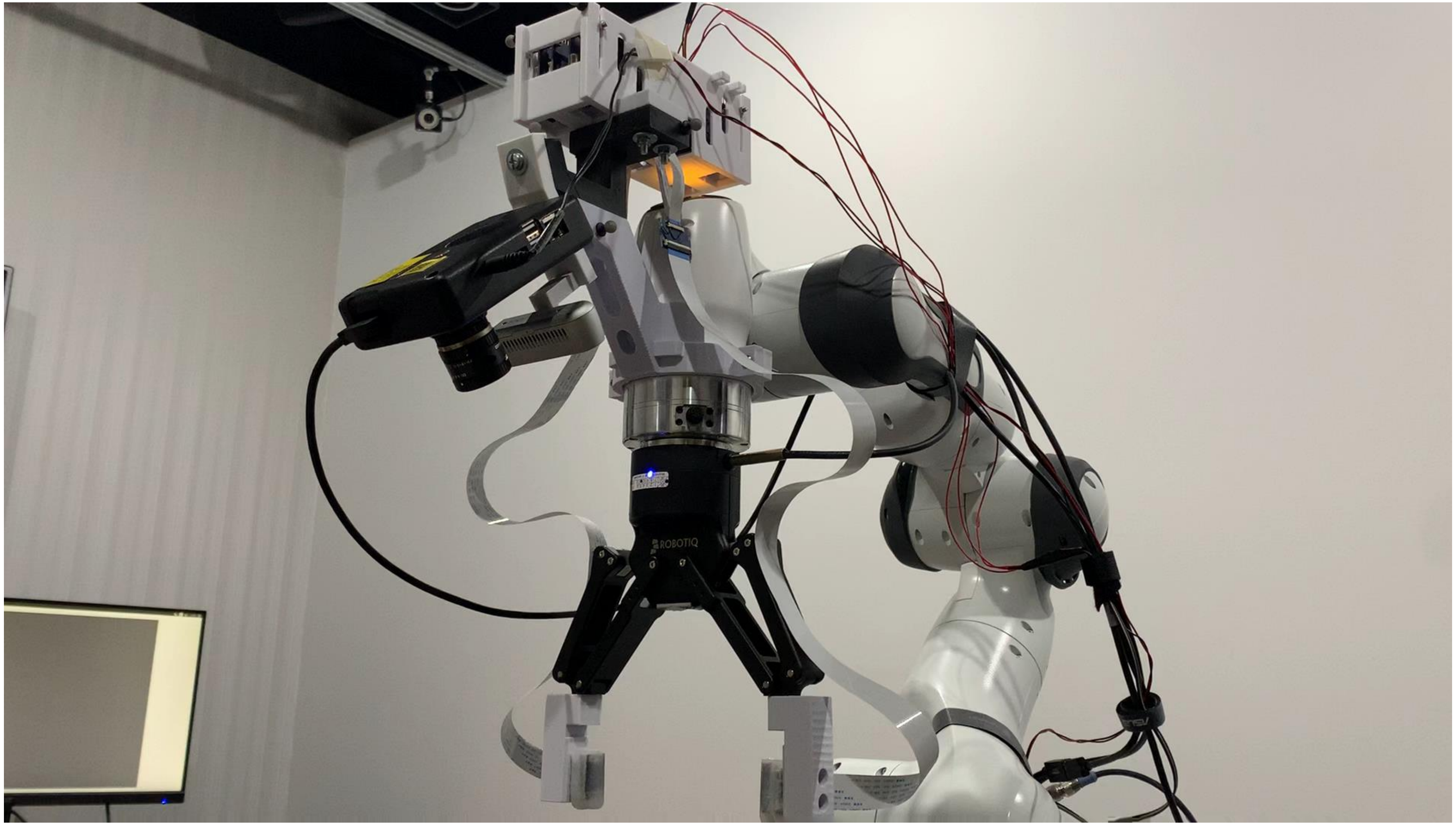
[1]. Shrestha, Sumit Bam, and Garrick Orchard. "Slayer: Spike layer error reassignment in time." *Advances in Neural Information Processing Systems*. 2018.

Visual-Tactile Spiking Neural Network (VT-SNN)

We tested VT-SNN framework on two robotic tasks:

- Container and weight classification
- Rotational slip classification

Robotic Setup



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Visual-Tactile Spiking Neural Network (VT-SNN)

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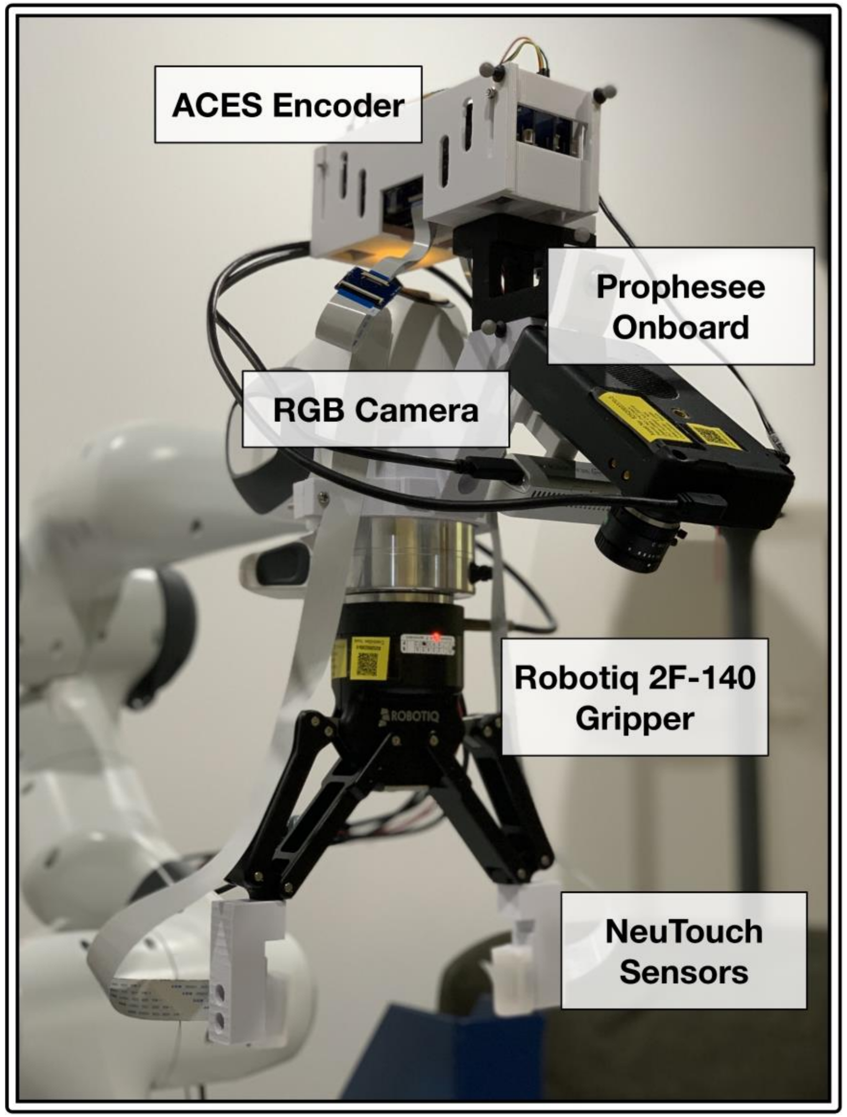
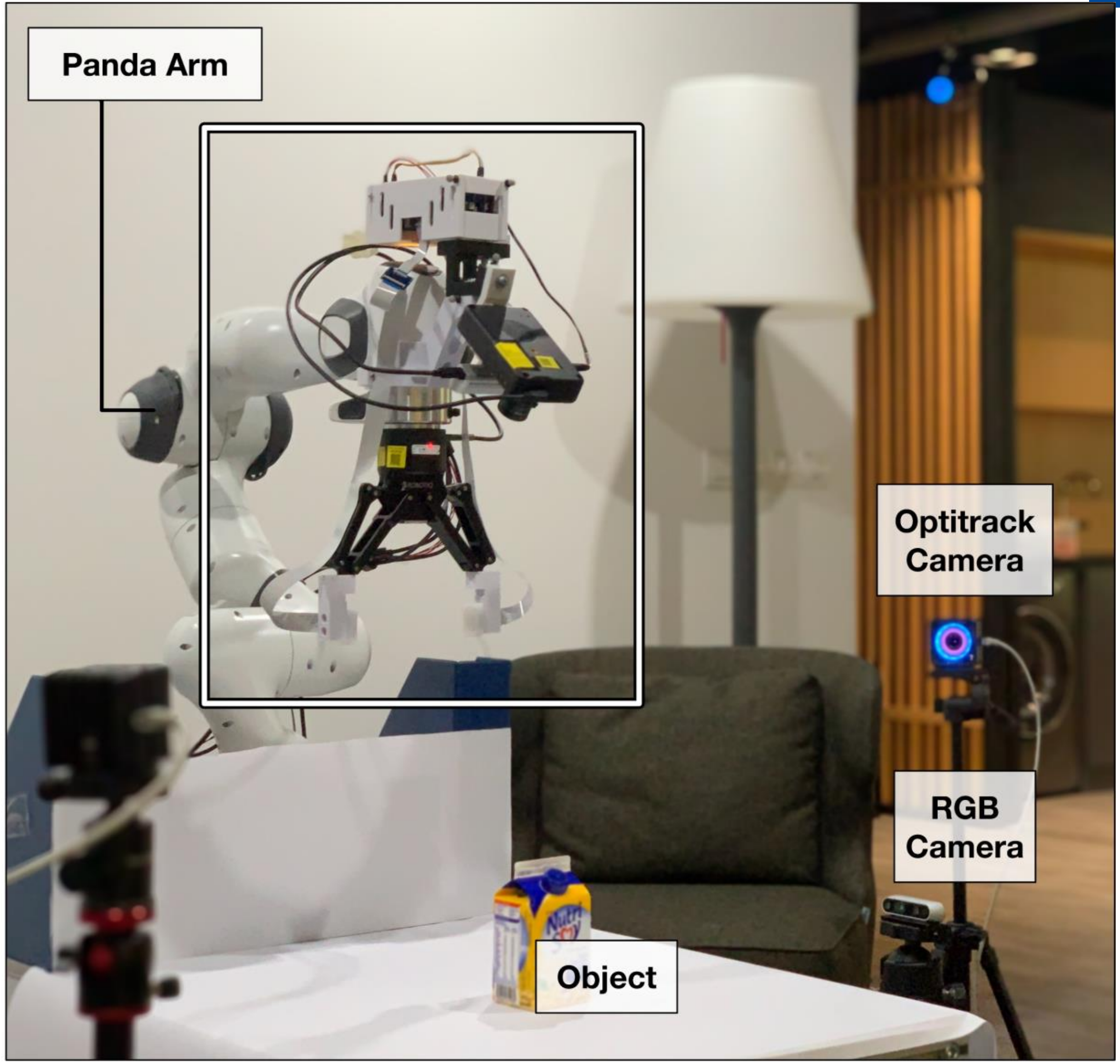
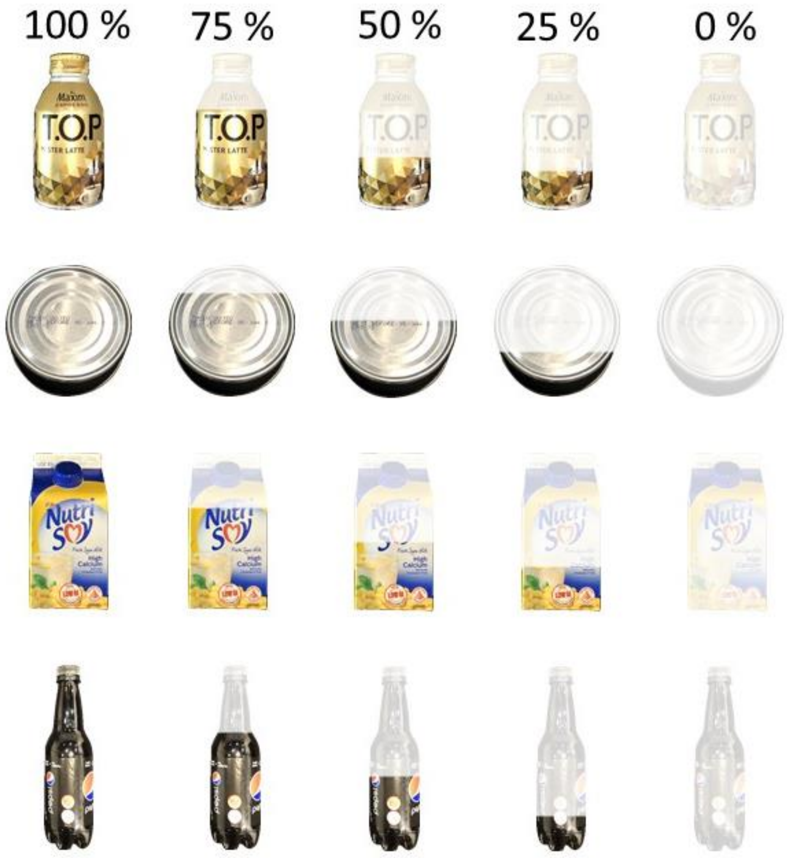




Container and Weight Classification



- 4 objects, 5 different weights = 20 classes
- 15 samples per each class = 300 data points
- 5-fold cross validation for testing the models

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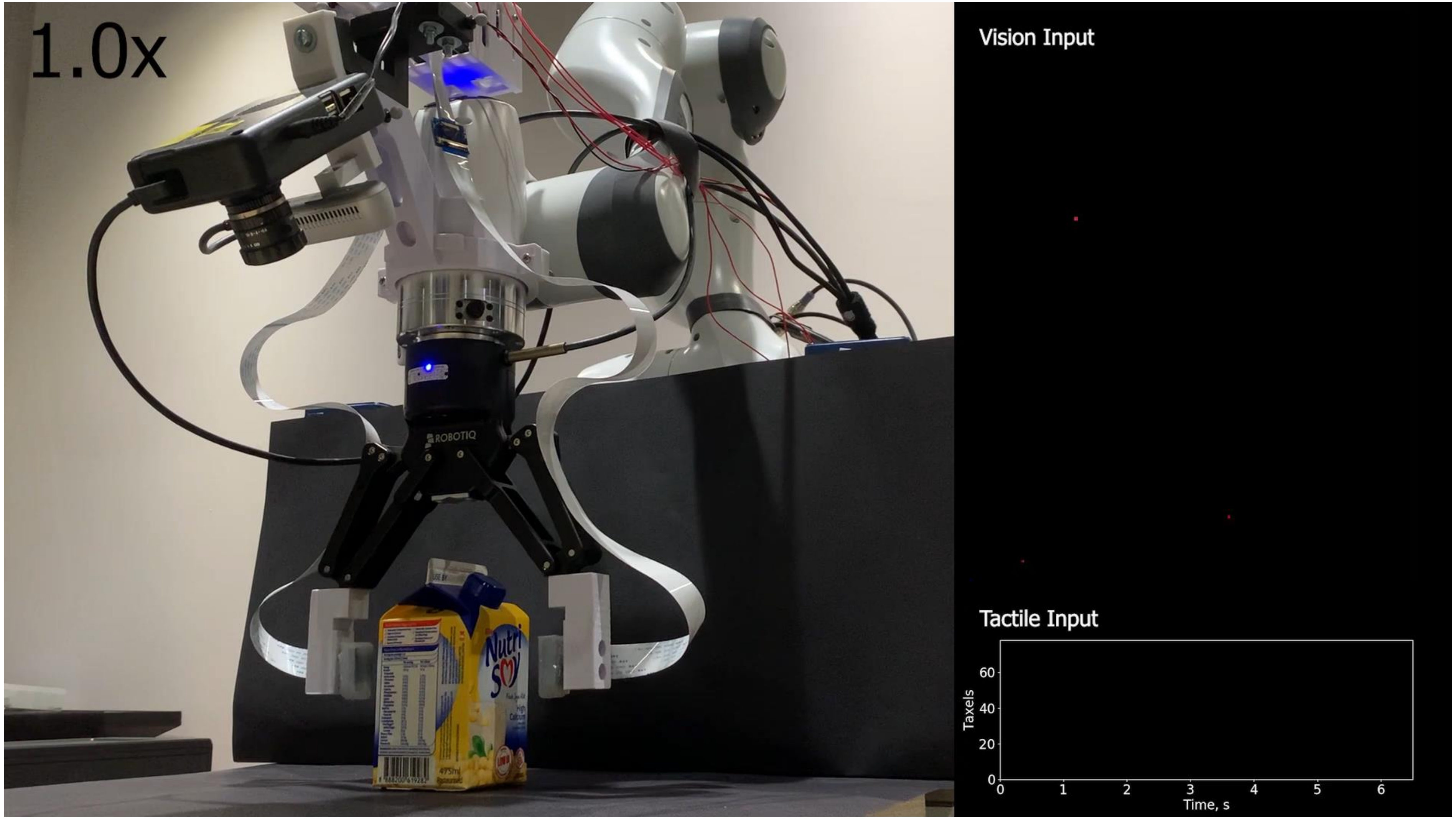
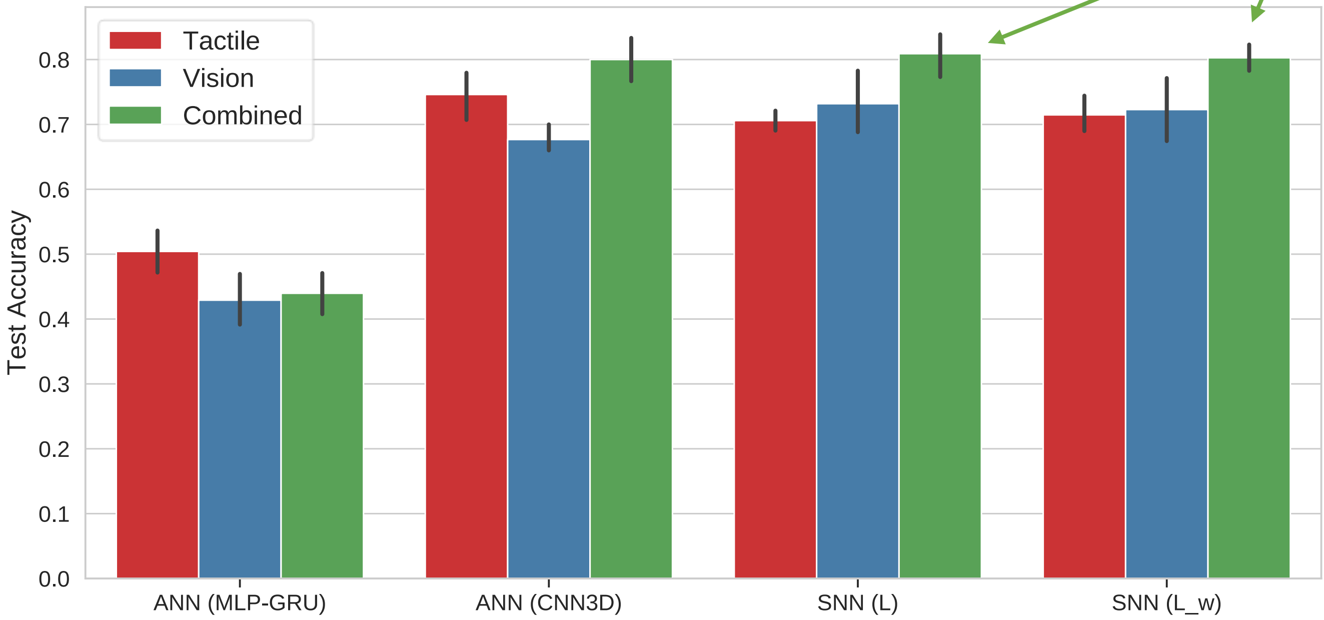
Container and Weight Classification: Data Collection Setup



Container and Weight Classification: Results (Final Accuracy)

Multimodal gives higher accuracy



SNN models perform better or comparable to ANN models

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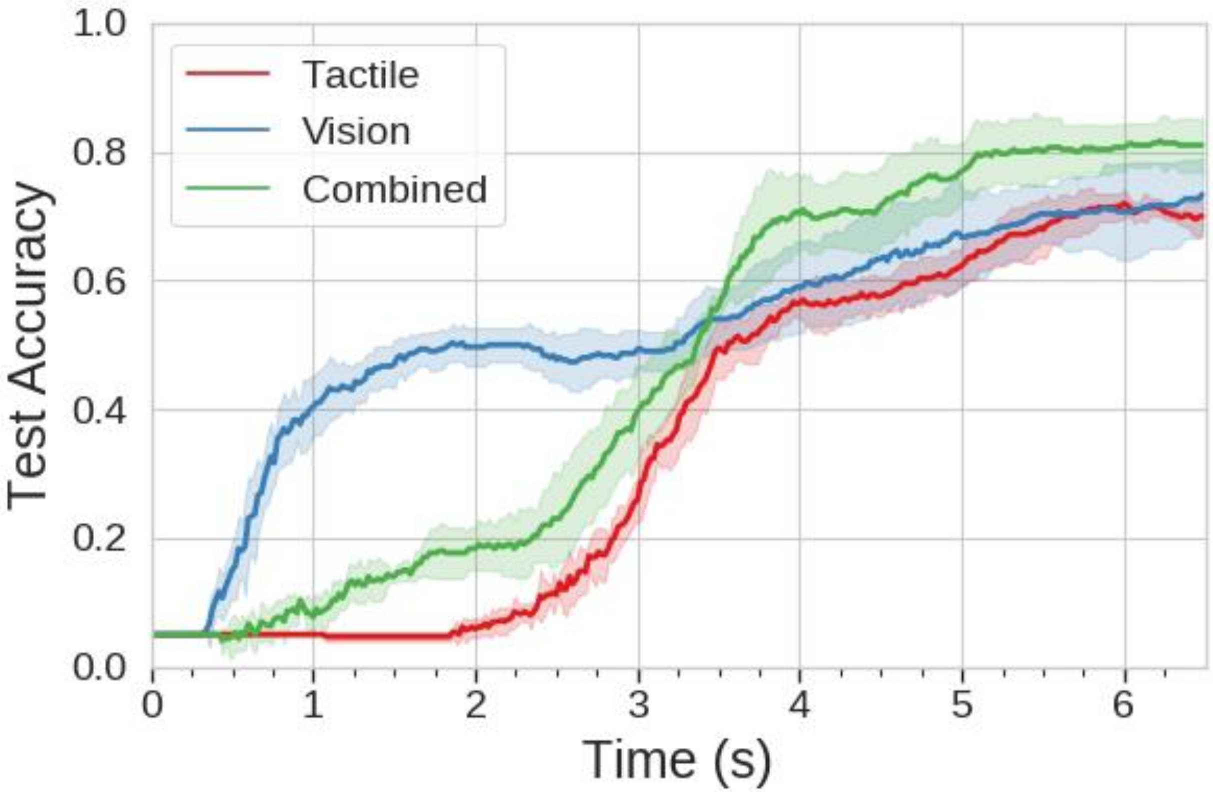
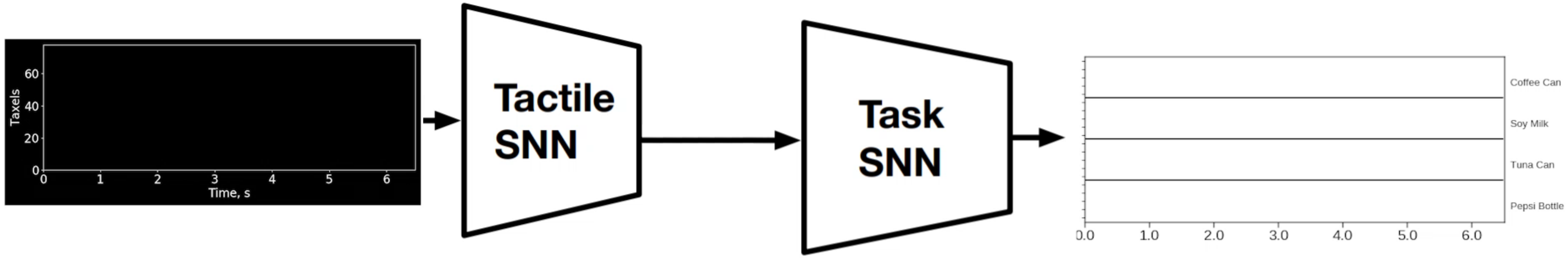
Container and Weight Classification: Results (Early Classification)

$$L = \frac{1}{2}\sum_{n=0}^{N_o}\left(\sum_{t=0}^{T} s^n(t) - \sum_{t=0}^{T} \tilde{s}^n(t)\right)^2$$

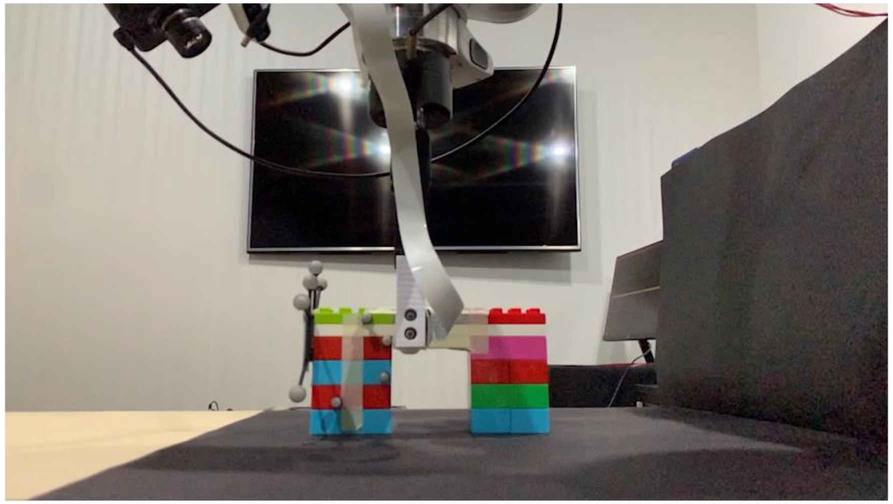


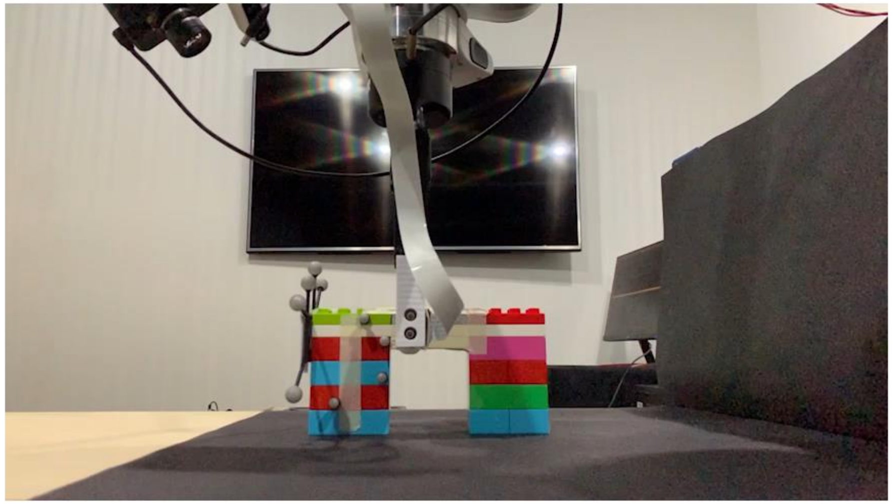
Container and Weight Classification: Output Example

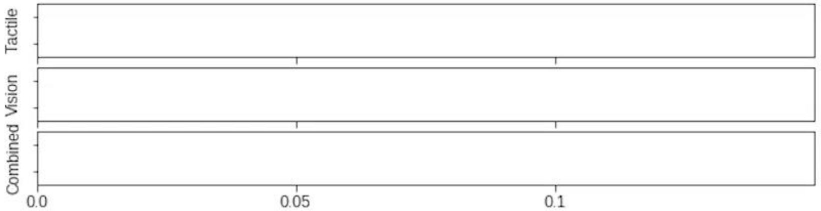


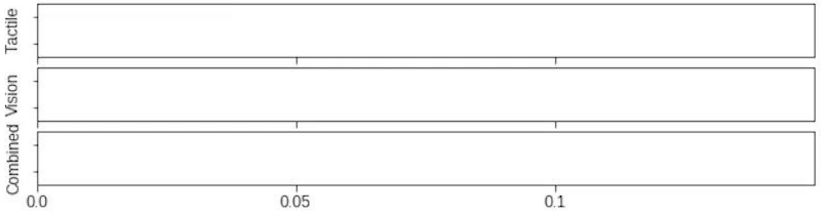
Rotational Slip Detection: Example of Output Neuron

0.02x



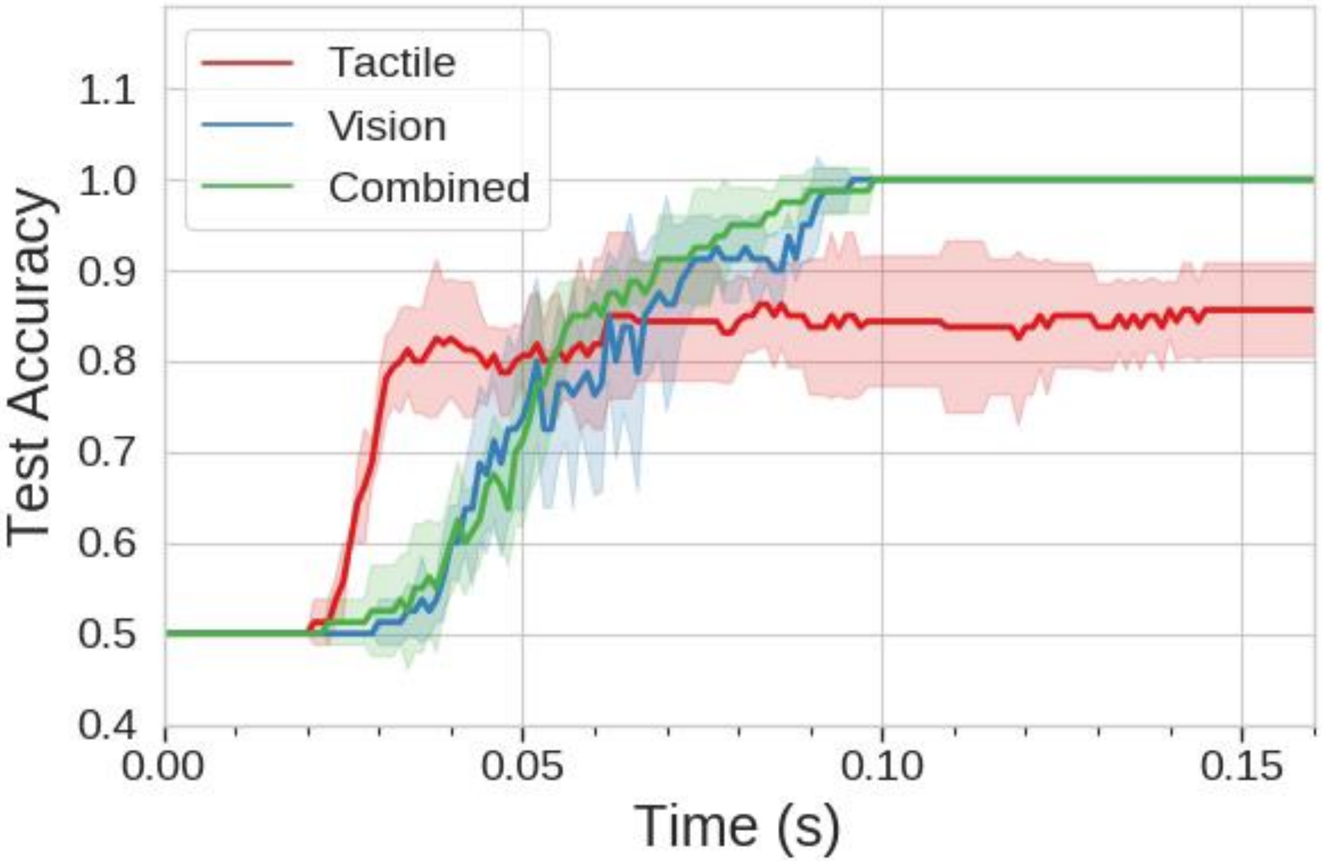






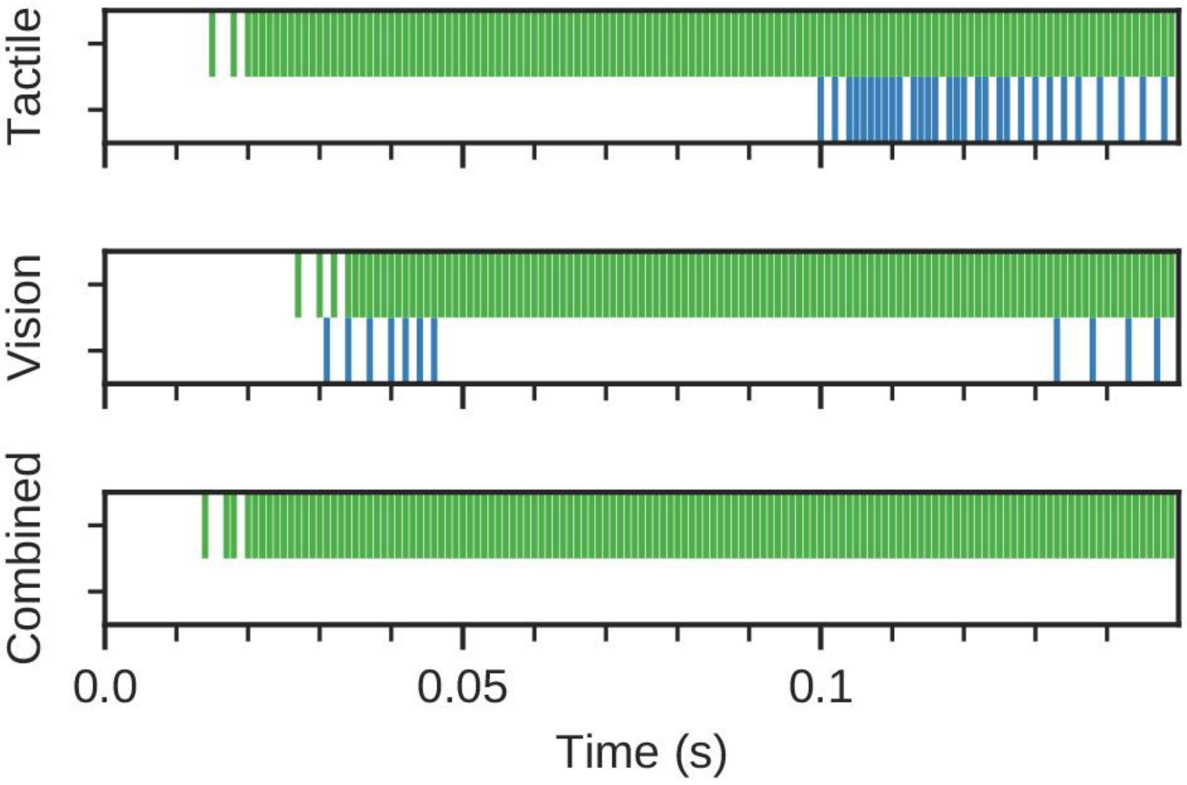
Rotational Slip Detection: Results (Early Classification)

$$L = \frac{1}{2}\sum_{n=0}^{N_o}\left(\sum_{t=0}^{T} s^n(t) - \sum_{t=0}^{T} \tilde{s}^n(t)\right)^2$$



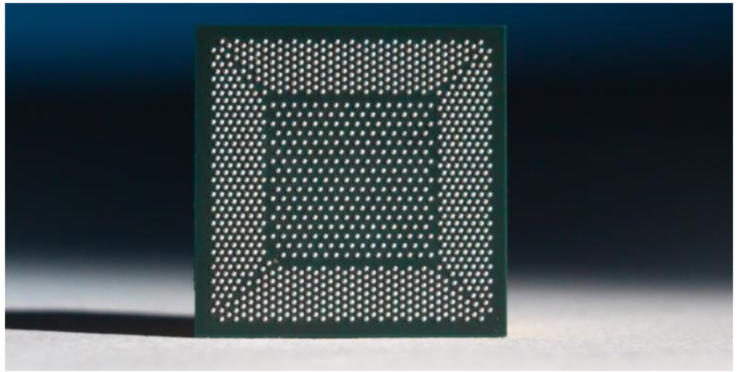
Rotational Slip Detection: Output Example with Weight Spike Count Loss

$$L_\omega = \frac{1}{2}\sum_{n=0}^{N_o}\left(\sum_{t=0}^{T}\omega(t)s^n(t) - \sum_{t=0}^{T}\omega(t)\tilde{s}^n(t)\right)^2$$



Power Utilization

Nvidia RTX 2080 Ti



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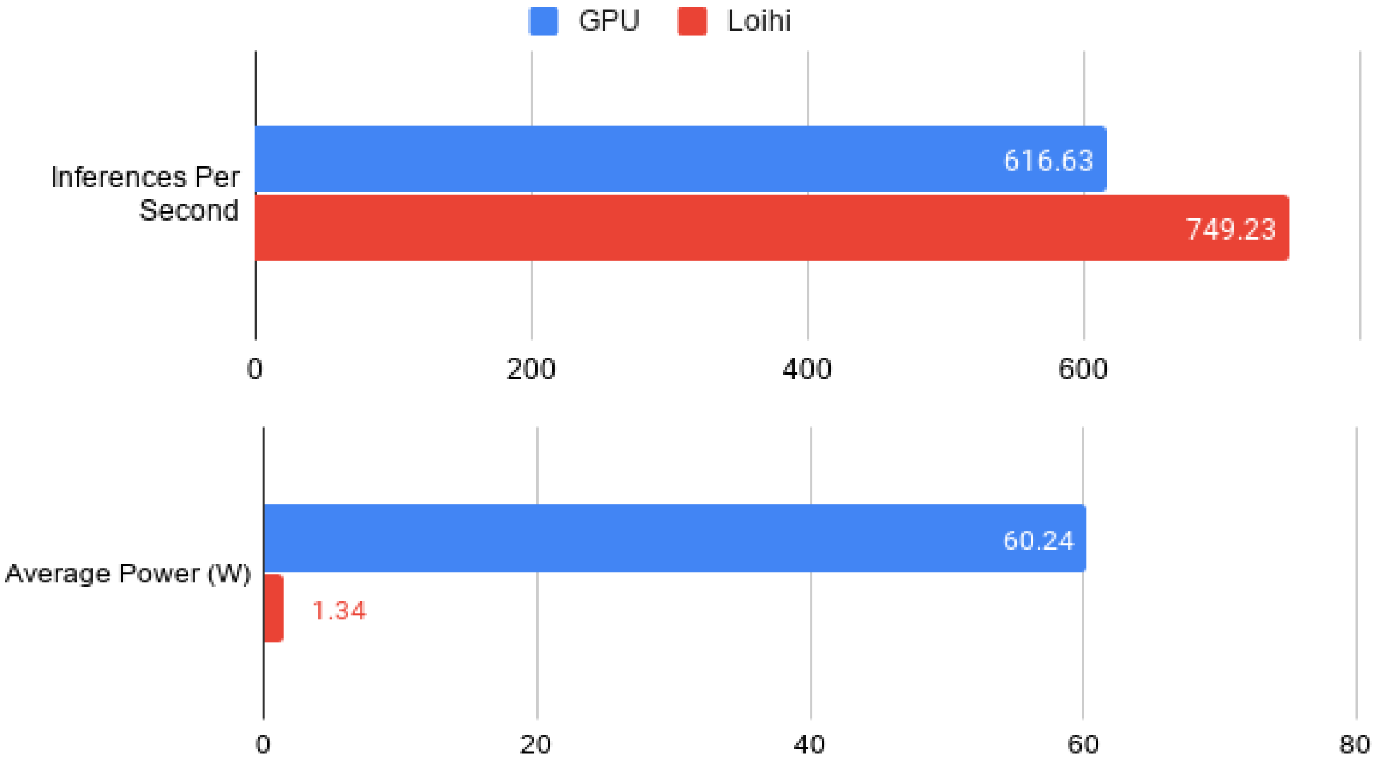

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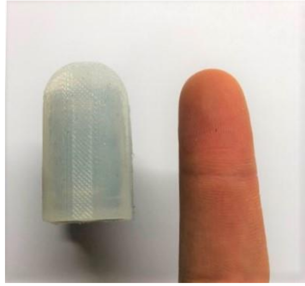
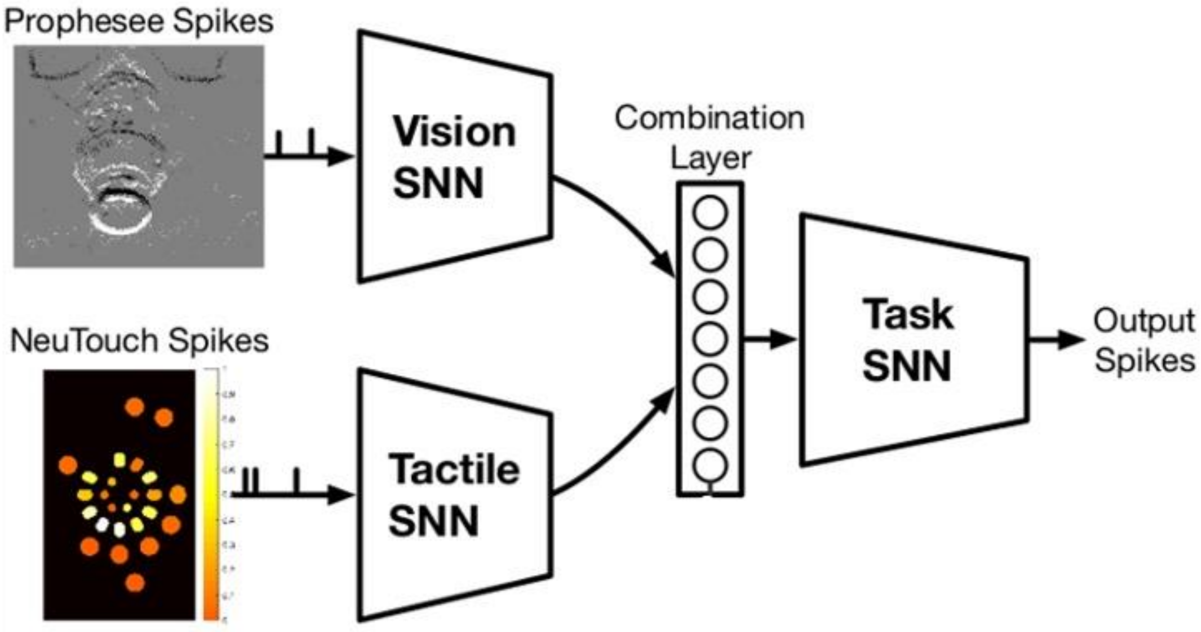
Conclusion

We proposed

- **NeuTouch** – event-based tactile sensor.
- **A VT-SNN** framework that combines side and touch event-based data.
- VT-SNN framework is tested on **two robot tasks**:
  1. Container and weight classification
  2. Rotational slip classification
- We put our datasets/code publicly available and can be found with following link:

  https://clear-nus.github.io/visuotactile/




Prophesee Spikes
Vision SNN
Combination Layer
NeuTouch Spikes
Tactile SNN
Task SNN
Output Spikes