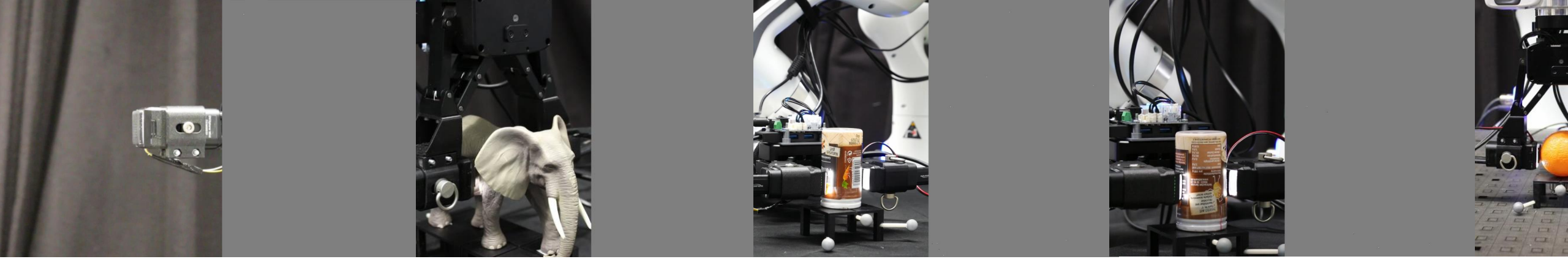
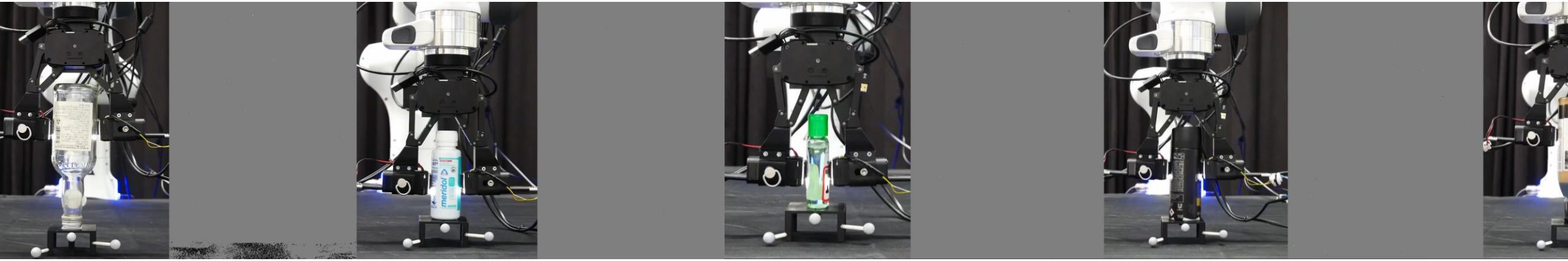


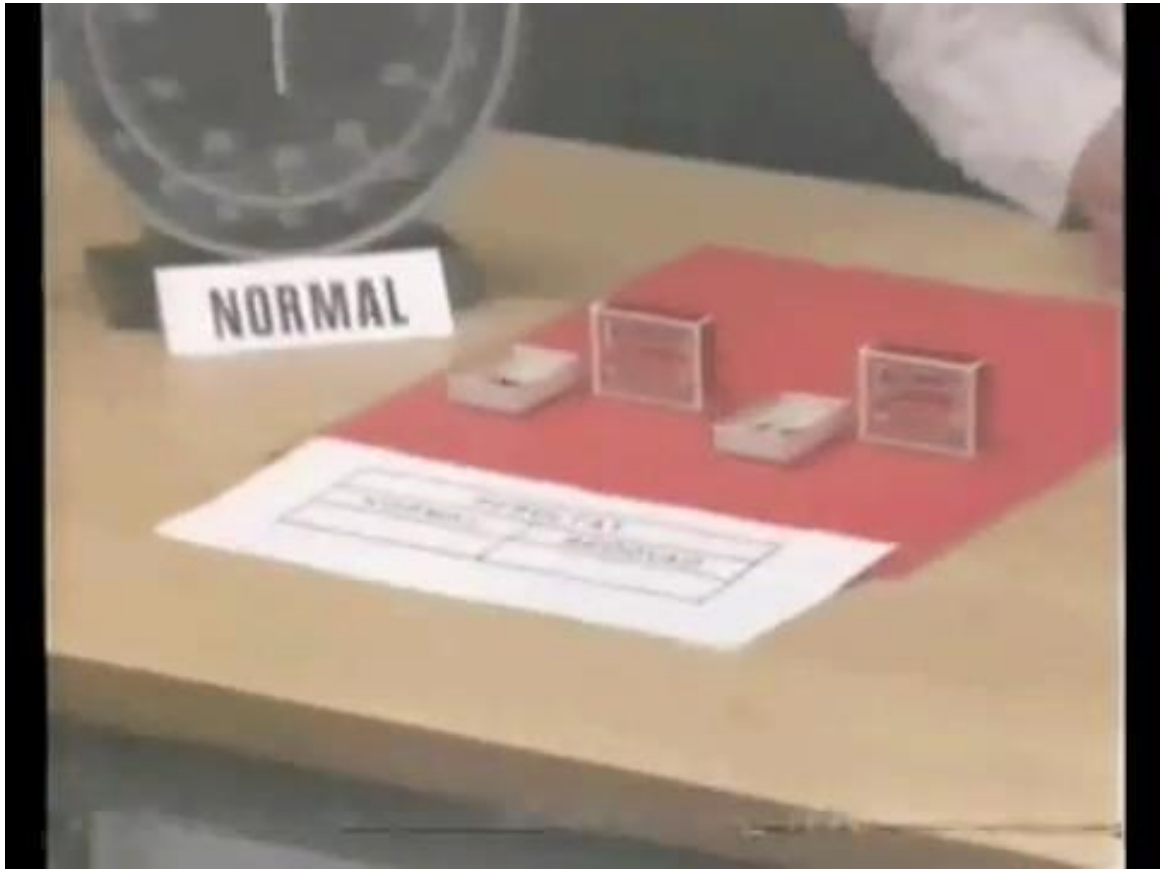
EVENT-BASED OPTICAL TACTILE SENSING FOR ROBOTIC MANIPULATION

Niklas Funk

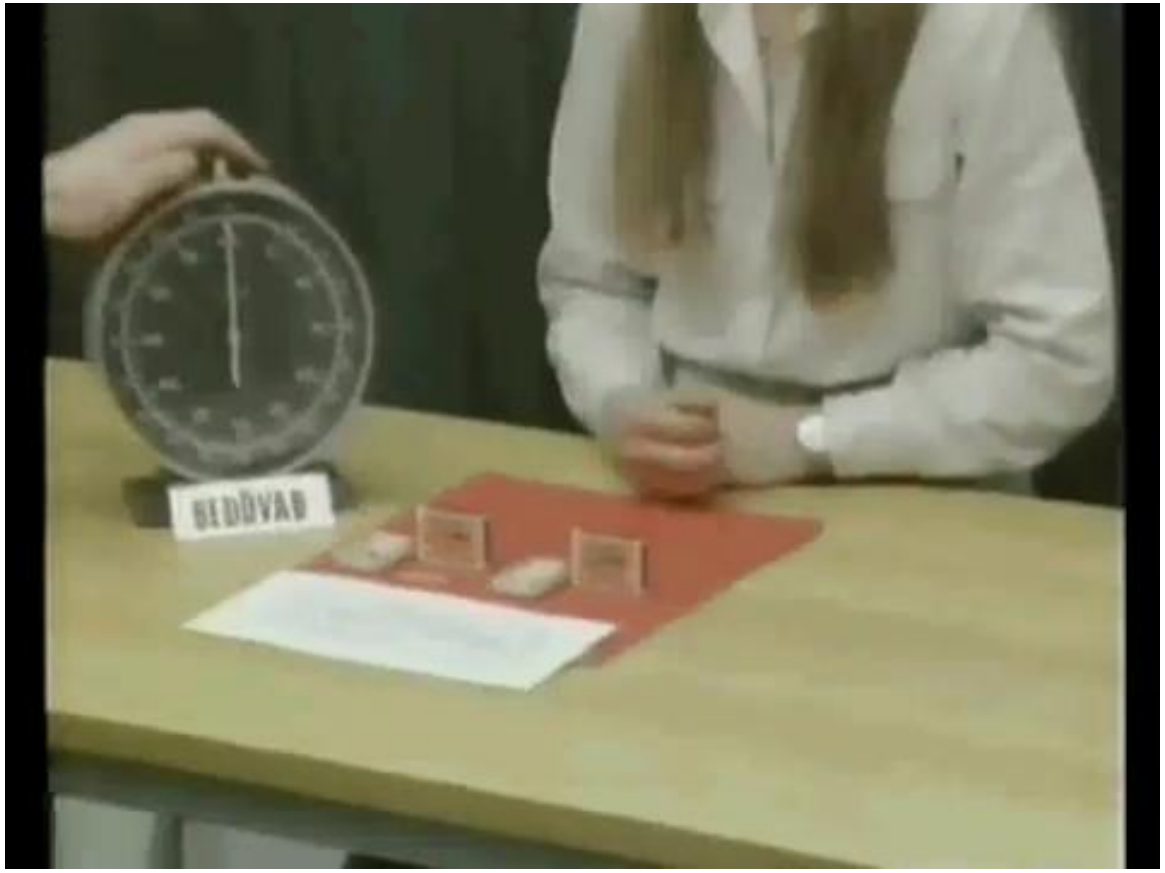
niklas@robot-learning.de



IMPORTANCE OF TACTILE SENSING FOR HUMAN MANIPULATION



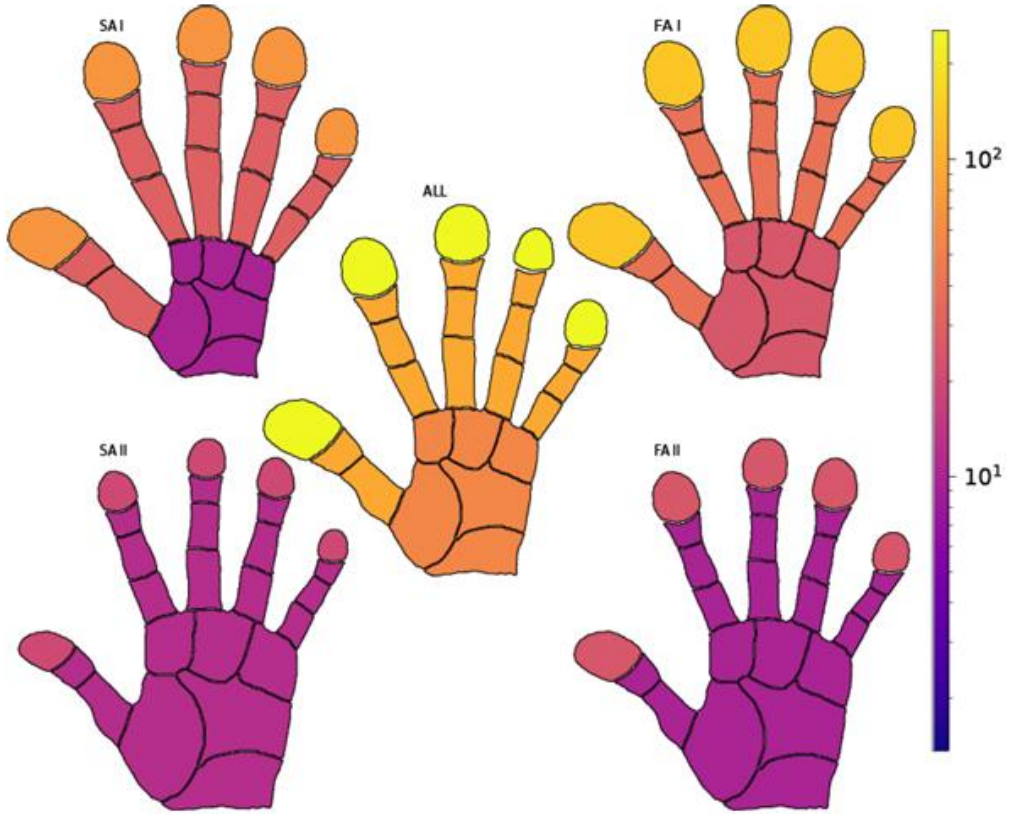
Normal, Pre-anesthetization Performance



Post-anesthetization Performance

From the lab of Dr. Roland Johansson, Dept. of Physiology, University of Umea, Sweden
Source: https://www.youtube.com/watch?v=0LfJ3M3Kn80

TOUCH SENSING IN HUMAN HANDS

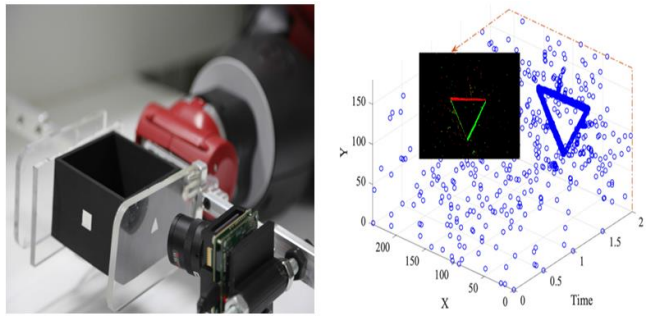


Tactile Innervation Densities in the Human Hand in (units/cm^2) [1]

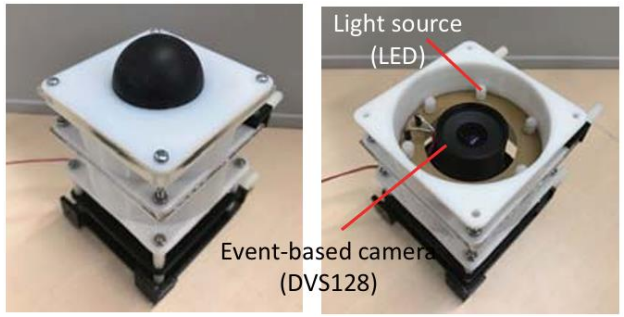
- ~18k tactile afferent fibers in the glabrous skin of young adults [1]
- Sub-mm spatial resolution in the fingertips [2]
- FA-II affarents sensitive to high-frequency vibrations 40-400Hz [3]

[1] Corniani et al., "Tactile innervation densities across the whole body." Journal of Neurophysiology 2020
[2] Abraira et al. "The sensory neurons of touch." Neuron 2013
[3] Johansson et al. "Coding and use of tactile signals from the fingertips in object manipulation tasks." Nature Reviews Neuroscience 2009

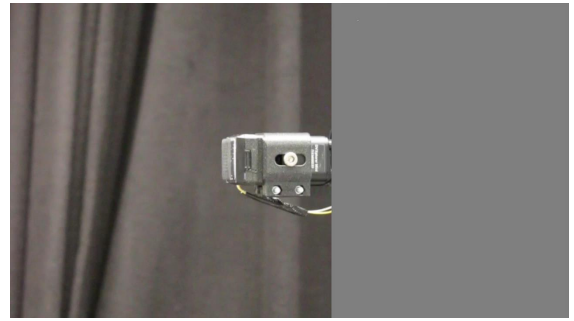
EVENT-BASED OPTICAL TACTILE SENSING



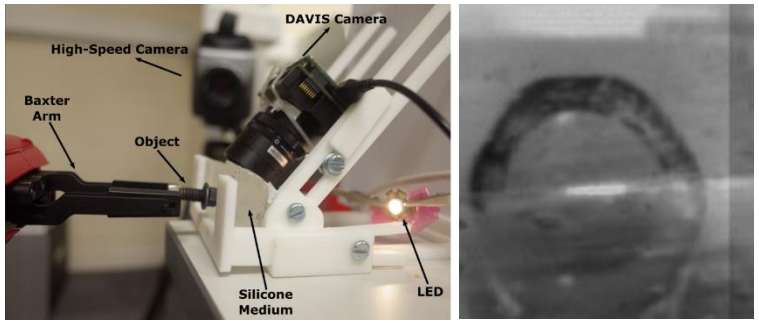
Muthusamy, et al. "Neuromorphic event-based slip detection and suppression in robotic grasping and manipulation." IEEE Access 2020.



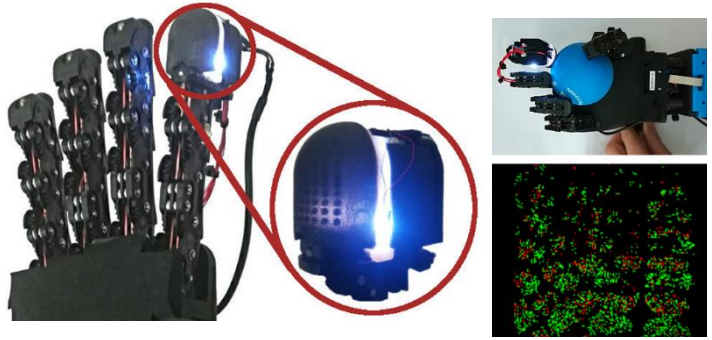
Kumagai et al. "Event-based tactile image sensor for detecting spatio-temporal fast phenomena in contacts." IEEE World Haptics Conference 2019.



Funk et al. “Evetac: An Event-based Optical Tactile Sensor for Robotic Manipulation", IEEE Transactions on Robotics, 2024.



Rigi et al. "A novel event-based incipient slip detection using dynamic active-pixel vision sensor (DAVIS)." Sensors 2018.



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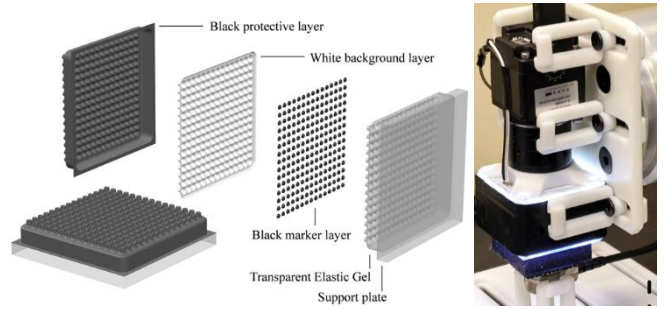
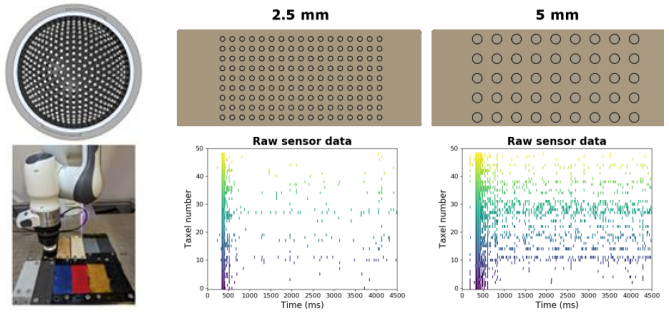
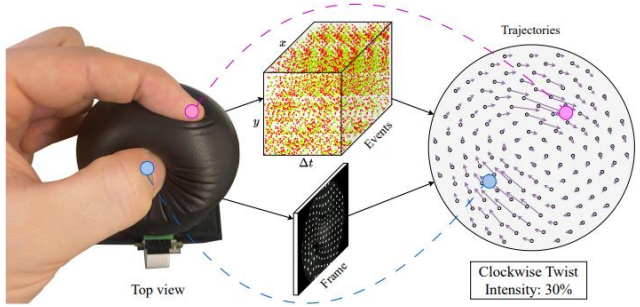


Yin, et al. "GelEvent—A Novel High-speed Tactile Sensor With Event Camera." IEEE Transactions on Instrumentation and Measurement 2025.

APPLICATIONS OF EVENT-BASED OPTICAL TACTILE SENSORS



Texture Recognition
Ward-Cherrier et al. "Neurotac: A neuromorphic optical tactile sensor applied to texture recognition." ICRA 2020



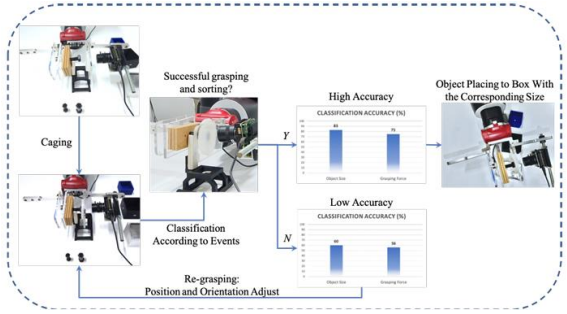
Haptic Gesture Recognition
Hoffmann et al. "From Soft Materials to Controllers with NeuroTouch: A Neuromorphic Tactile Sensor for Real-Time Gesture Recognition." arXiv preprint 2025

Slip Detection & Grasp Control
Funk et al. “Evetac: An Event-based Optical Tactile Sensor for Robotic Manipulation", IEEE Transactions on Robotics, 2024.

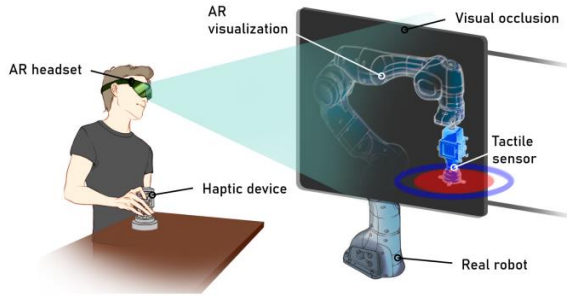
Rigi et al. "A novel event-based incipient slip detection using dynamic active-pixel vision sensor (DAVIS)." Sensors 2018.

Muthusamy, et al. "Neuromorphic event-based slip detection and suppression in robotic grasping and manipulation." IEEE Access 2020

Reinold et al. "Combined Physics and Event Camera Simulator for Slip Detection." WACVW 2025

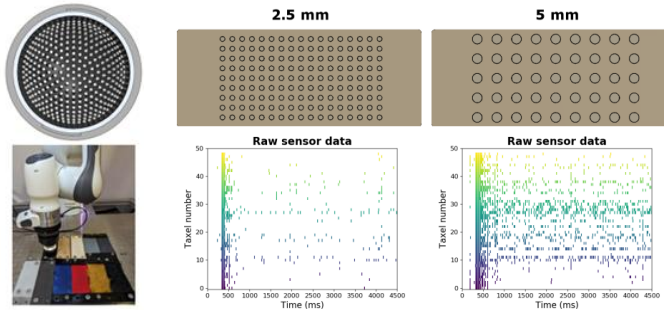


Object & Material Classification
Huang et al. "Neuromorphic vision based contact-level classification in robotic grasping applications." Sensors 2020



Haptic Teleoperation
Mukashev et al. "E-BTS: Event-Based Tactile Sensor for Haptic Teleoperation in Augmented Reality." IEEE Transactions on Robotics 2024

APPLICATIONS OF EVENT-BASED OPTICAL TACTILE SENSORS



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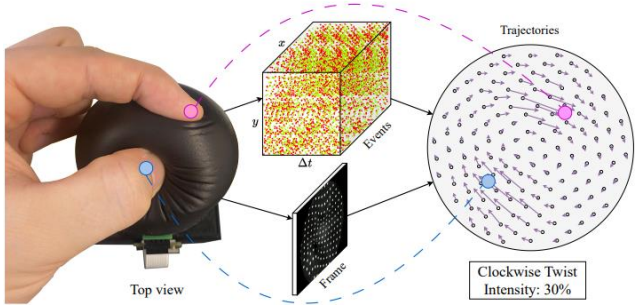

Haptic Gesture Recognition
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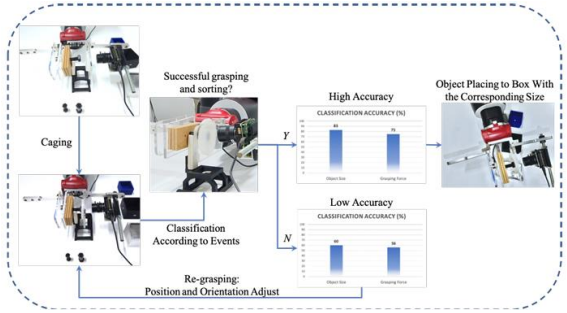

Object & Material Classification
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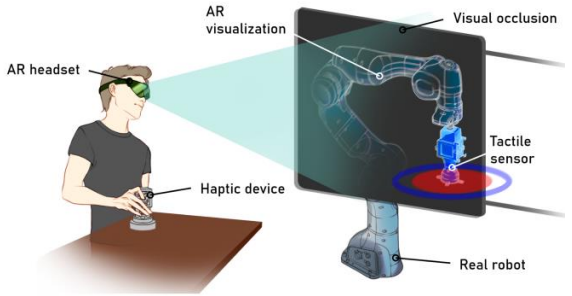


Haptic Teleoperation
Mukashev et al. "E-BTS: Event-Based Tactile Sensor for Haptic Teleoperation in Augmented Reality." IEEE Transactions on Robotics 2024

EVETAC – EVENT-BASED TACTILE SENSING

Event-based Camera

Housing

Lighting

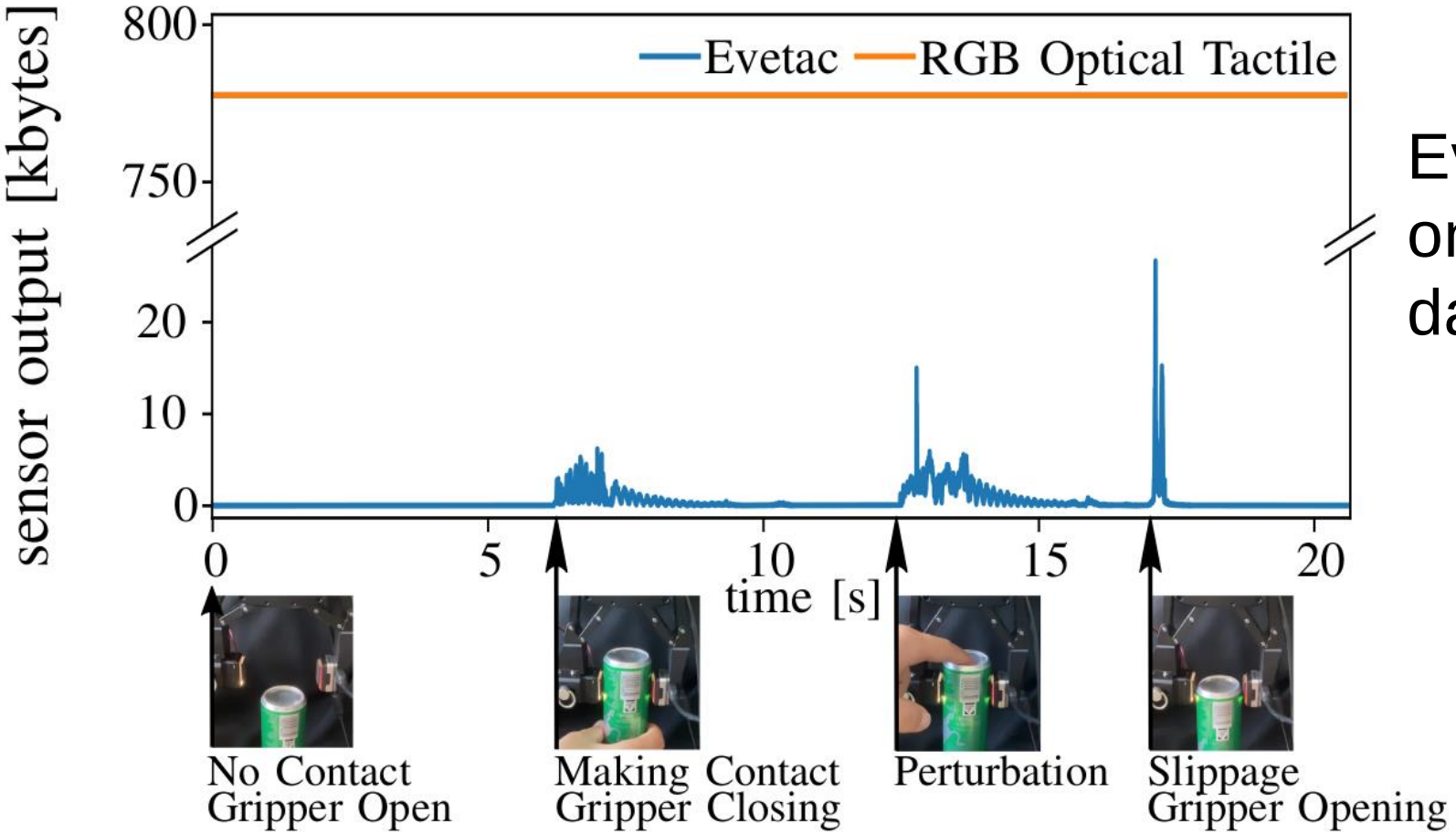
Gel

Funk et al. “Evetac: An Event-based Optical Tactile Sensor for Robotic Manipulation", *T-RO 2024.*

EVETAC‘S RAW OUTPUT

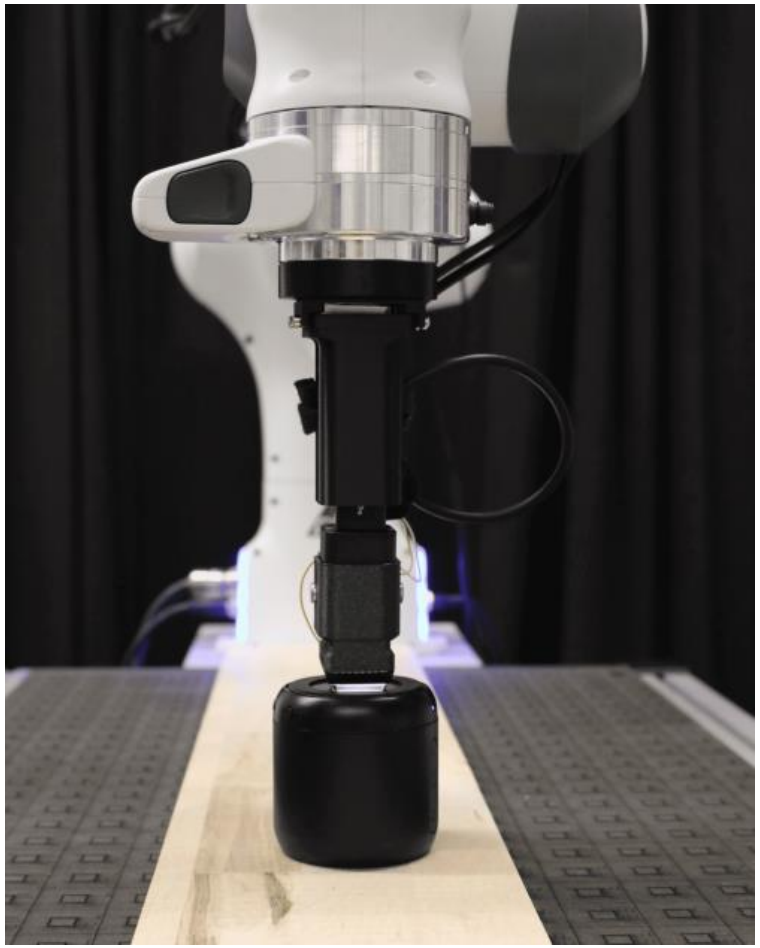
EVETAC VS RGB OPTICAL TACTILE SENSOR

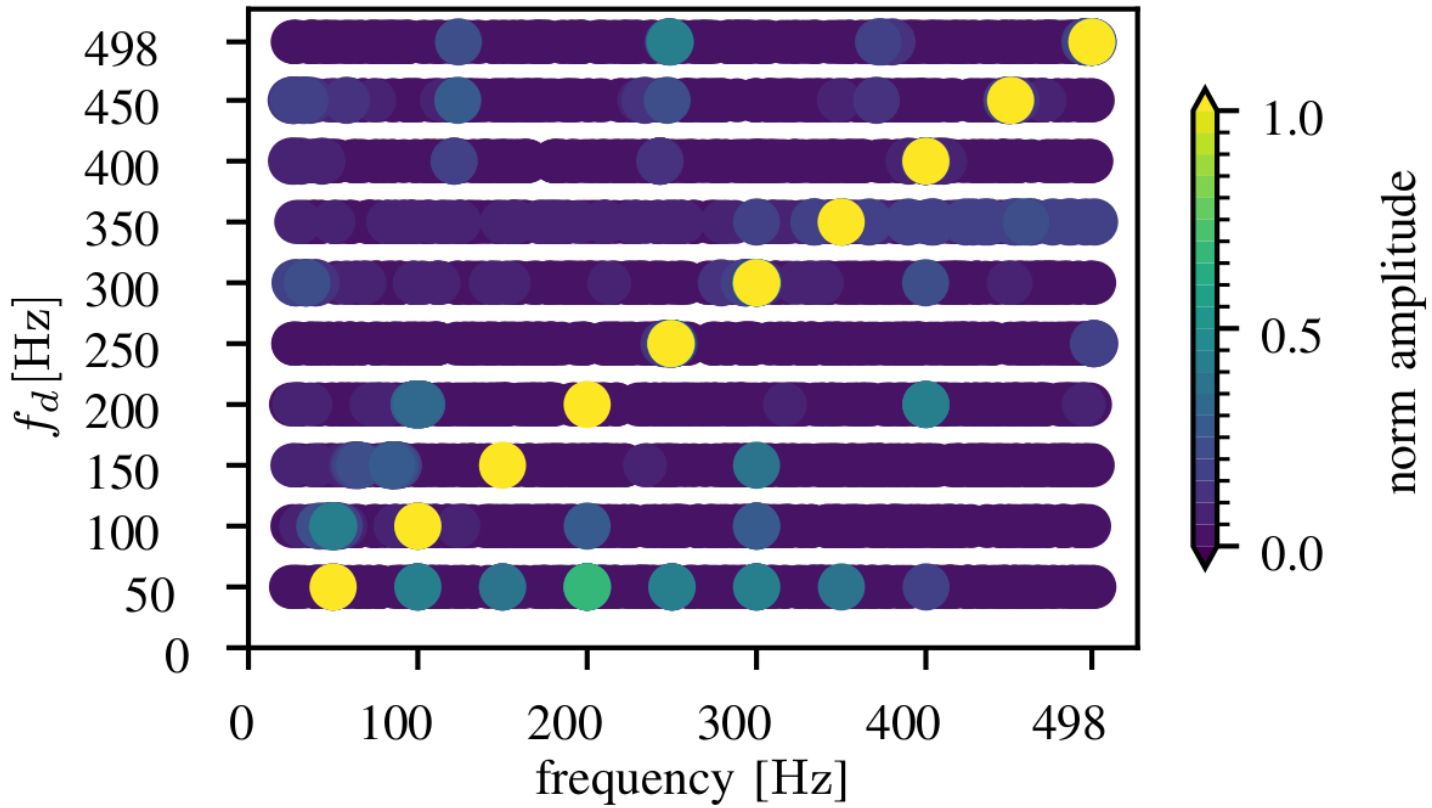
DATA RATE RESULTS



Evetac outputs only **1.7%** of the data.

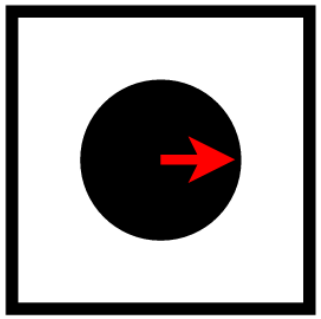
SENSING VIBRATIONS



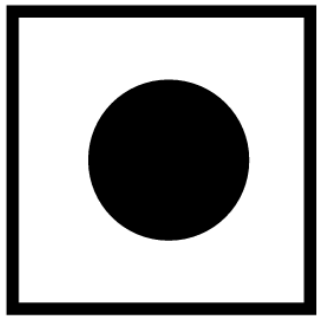


MODEL-BASED DOT TRACKING

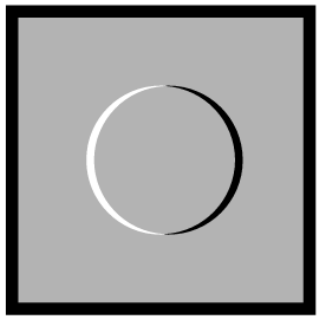
Moving dots generate events:



$t = t_i$



$t = t_{i+1}$



$\mathcal{S}_{\mathrm{E}}(t_{i+1})$

Model-based tracking objective (The events have to be explained by dot movements):

$$f = \|\boldsymbol{x}_k - (\boldsymbol{x}^m_{j\to k} + \tilde{\boldsymbol{c}})\|_2^2 = \|\boldsymbol{x}_k - (r\boldsymbol{x}_k/\|\boldsymbol{x}_k\|_2 + \tilde{\boldsymbol{c}})\|_2^2$$

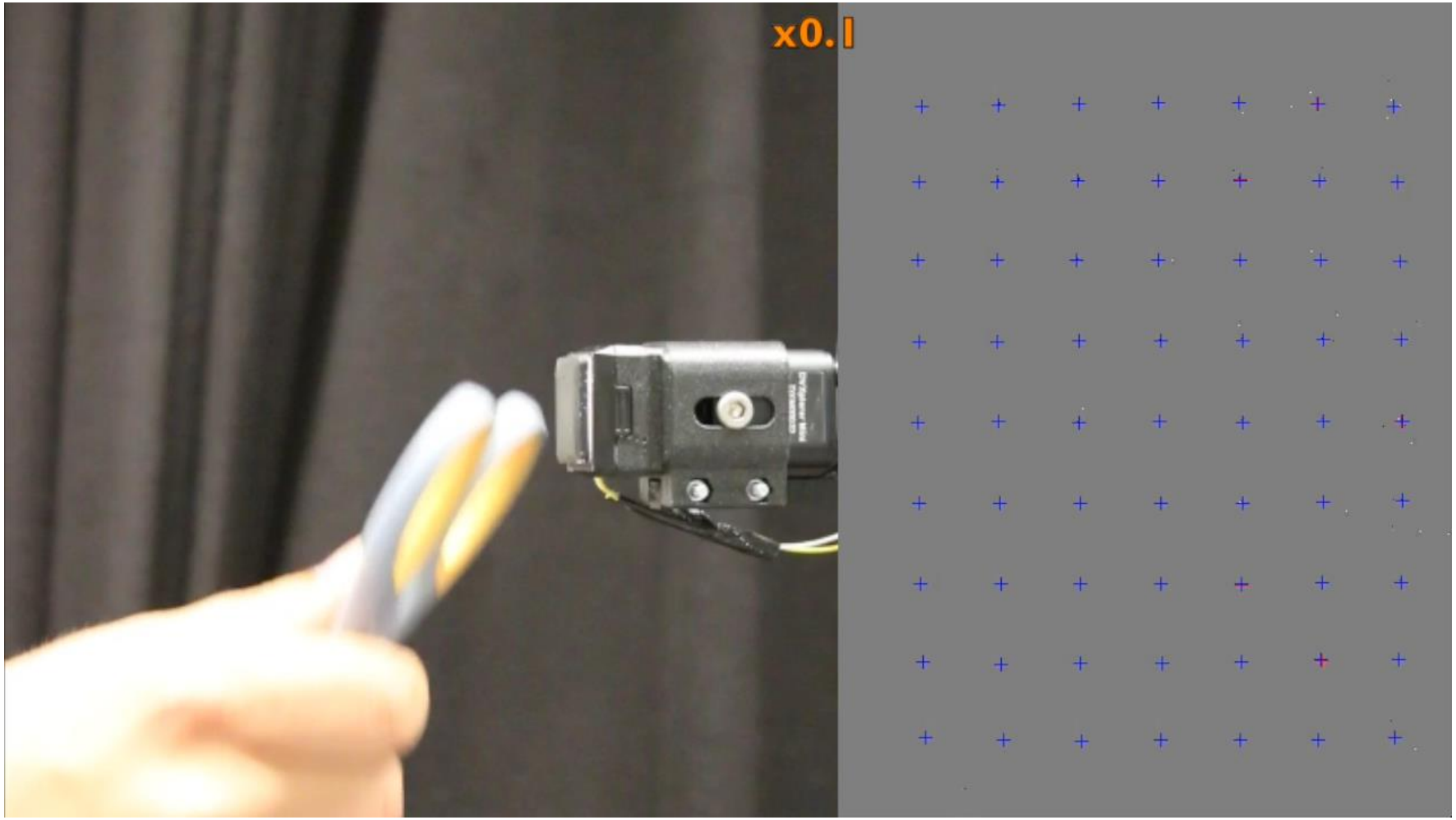
Regularized dot-tracking (The dots should remain in a grid-like structure):

$$f_{\mathrm{reg}} = f + w_{\mathrm{dist}} f_{\mathrm{dist}} = f + w_{\mathrm{dist}} \left(\|(\boldsymbol{c}_i^1 + \tilde{\boldsymbol{c}}) - \boldsymbol{c}_i^2\|_2^2 - d_{1,2} \right)^2$$

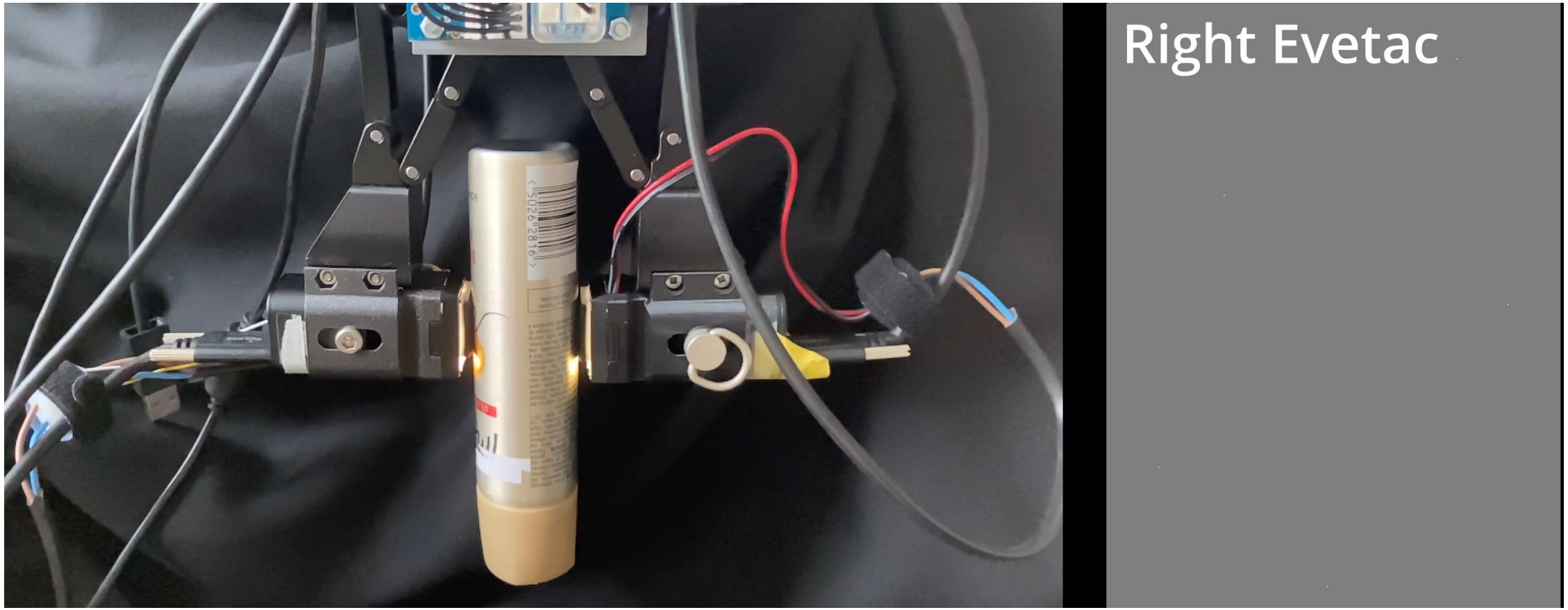
Ni et al. “Visual tracking using neuromorphic asynchronous event-based cameras.” *Neural computation, 2015*.

DOT TRACKING – EFFECTIVENESS OF REGULARIZER

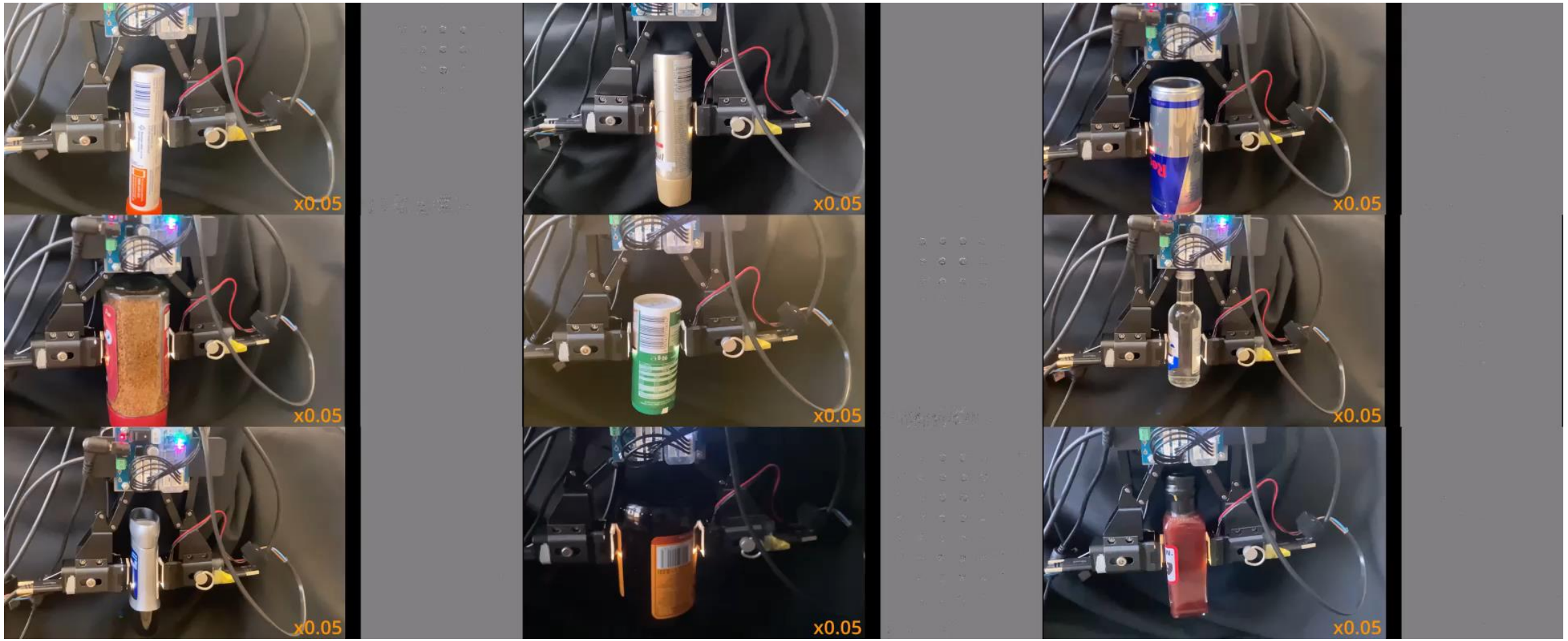
UNREGULARIZED VERSION VS REGULARIZED VERSION



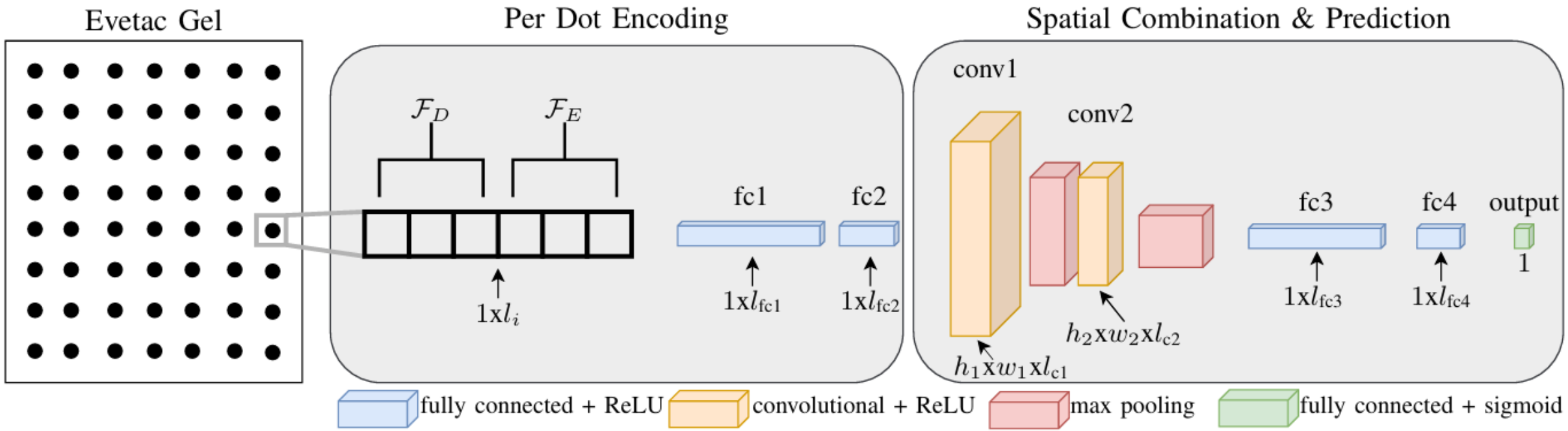
DATA-DRIVEN SLIP DETECTION – DATA COLLECTION



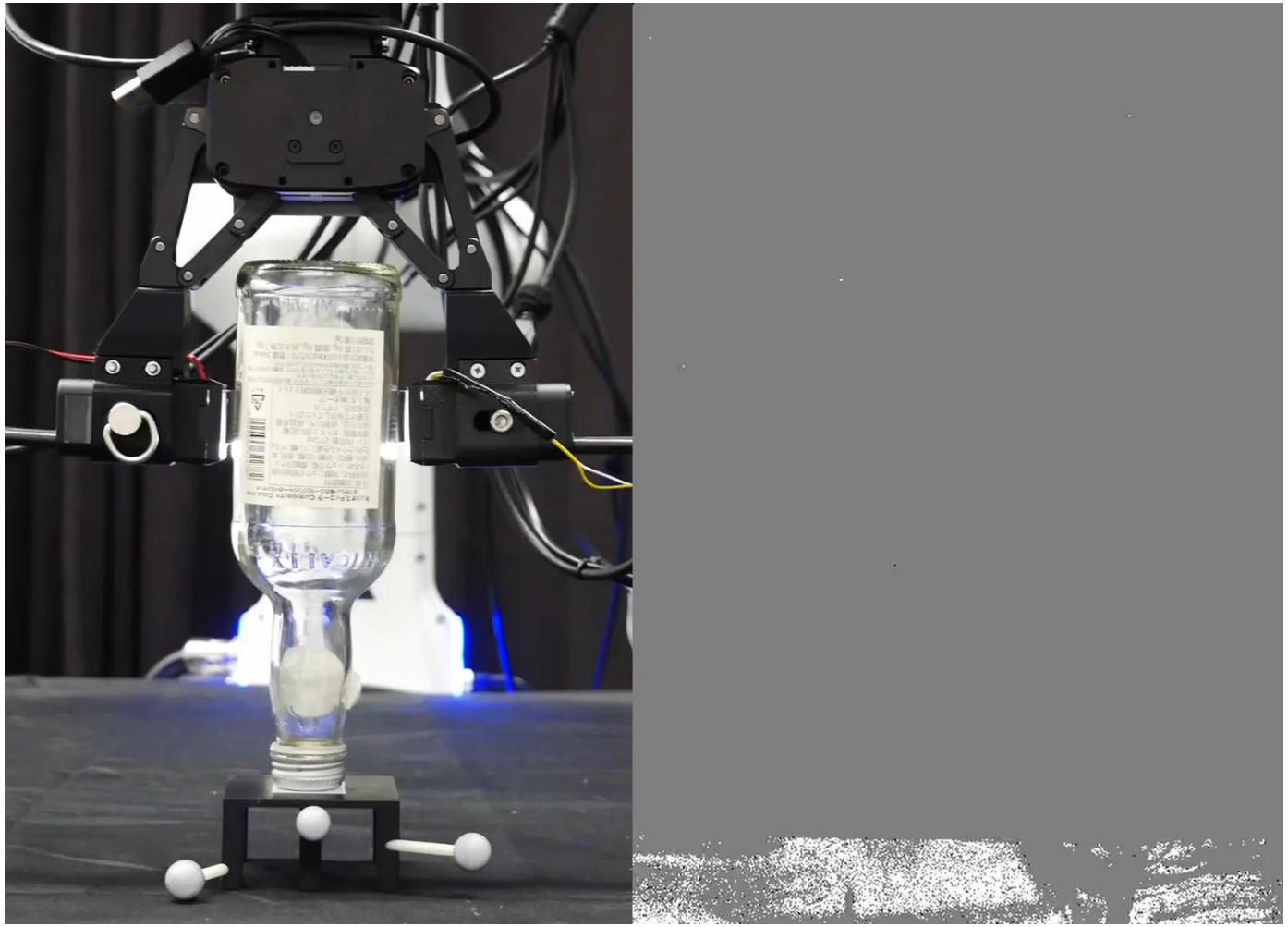
DATA COLLECTION FOR ALL TRAINING OBJECTS (SPEED X0.05)



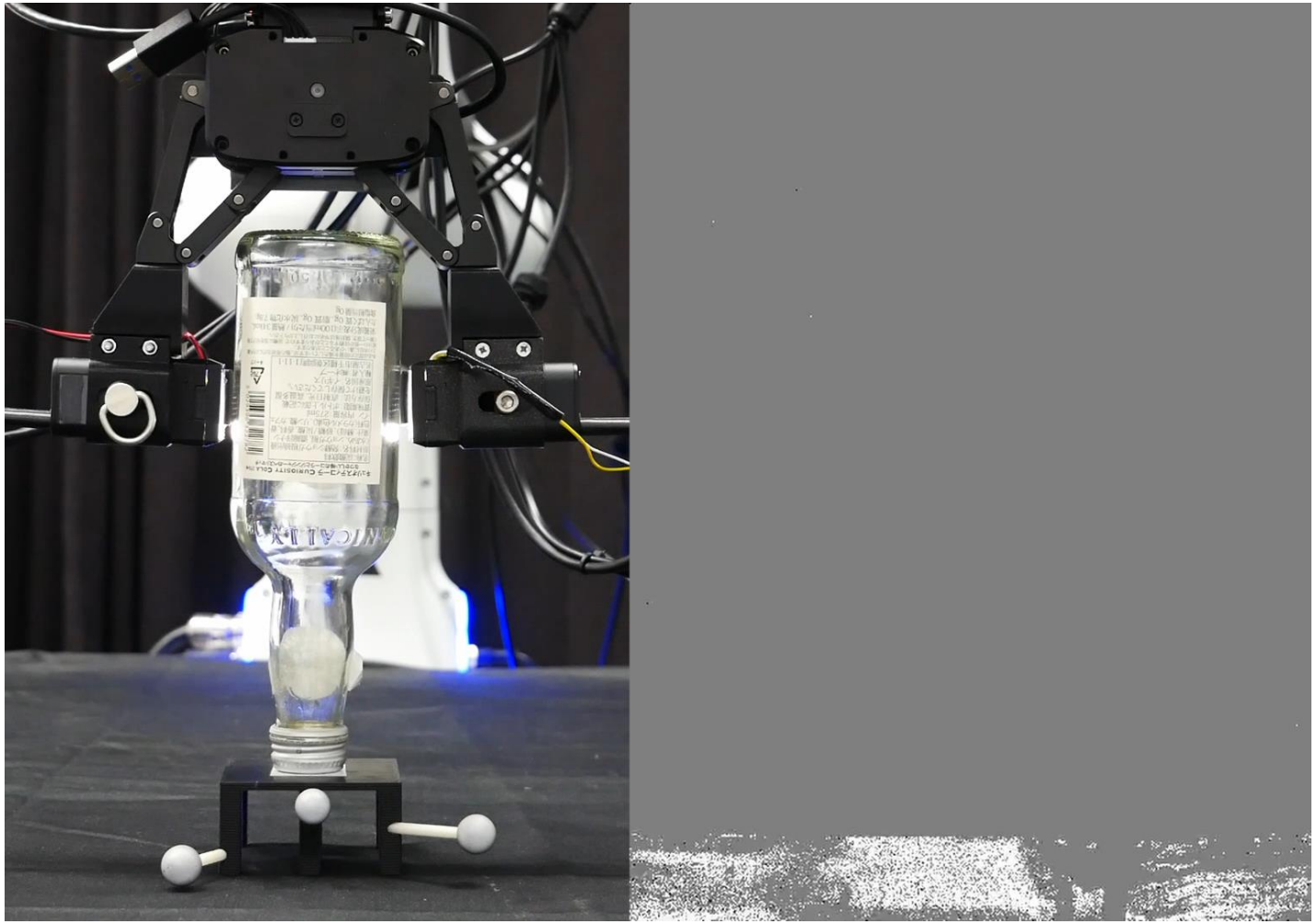
SLIP DETECTION - NETWORK ARCHITECTURE



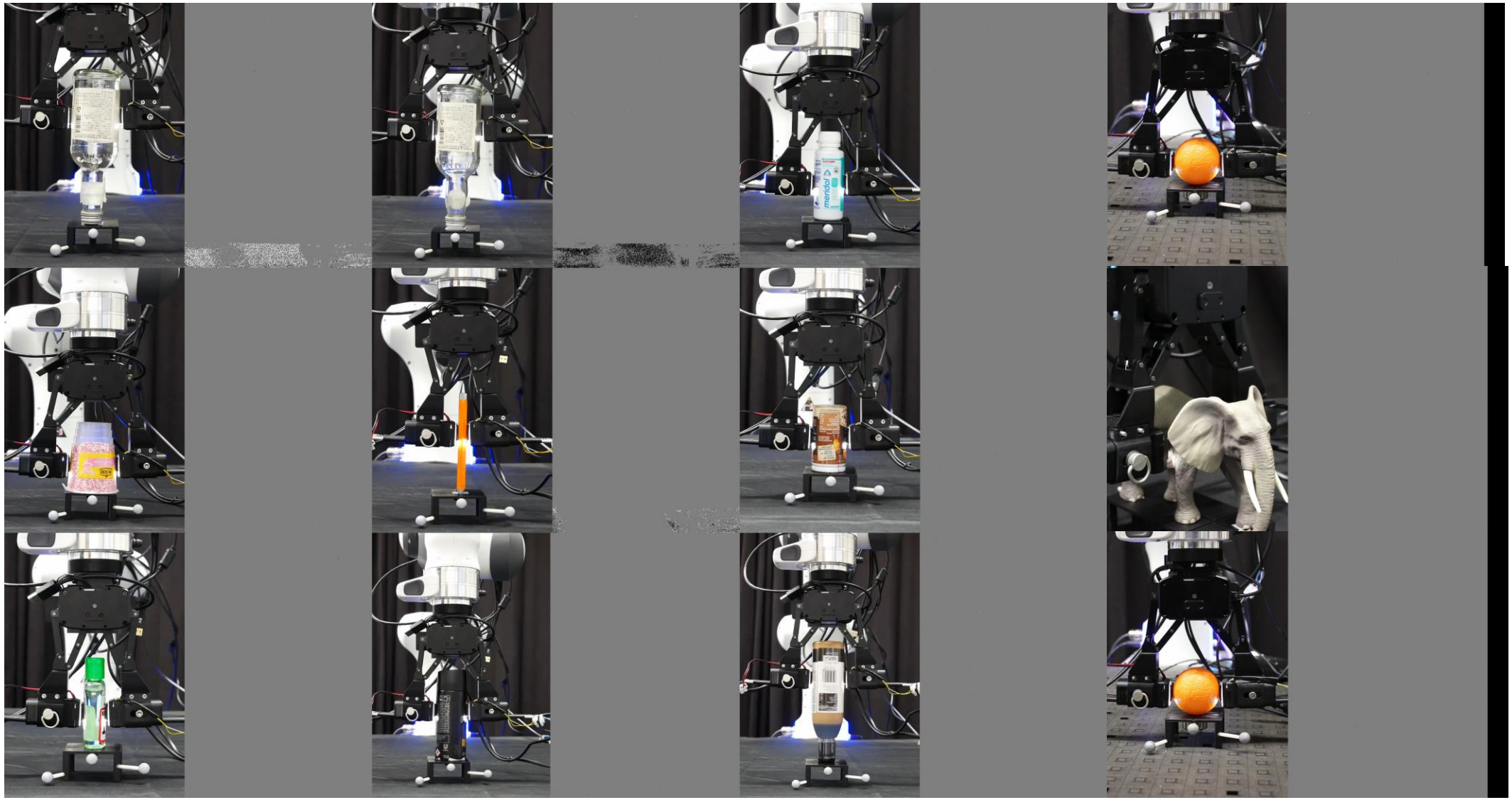
CLOSED-LOOP GRASP CONTROL EXPERIMENT – CONTROLLER DEACTIVATED



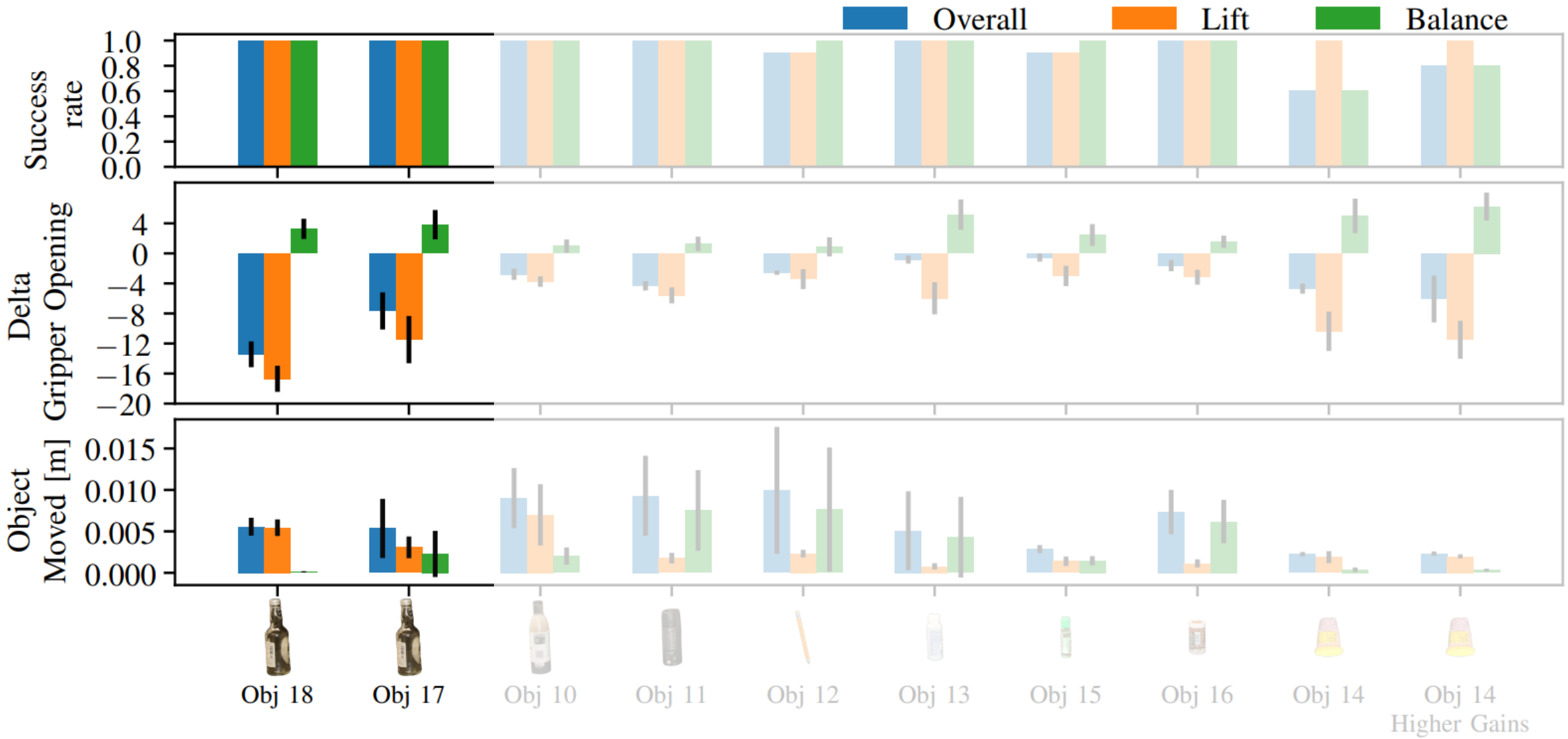
GRASP CONTROLLER ACTIVE



GRASP CONTROLLER GENERALIZATION

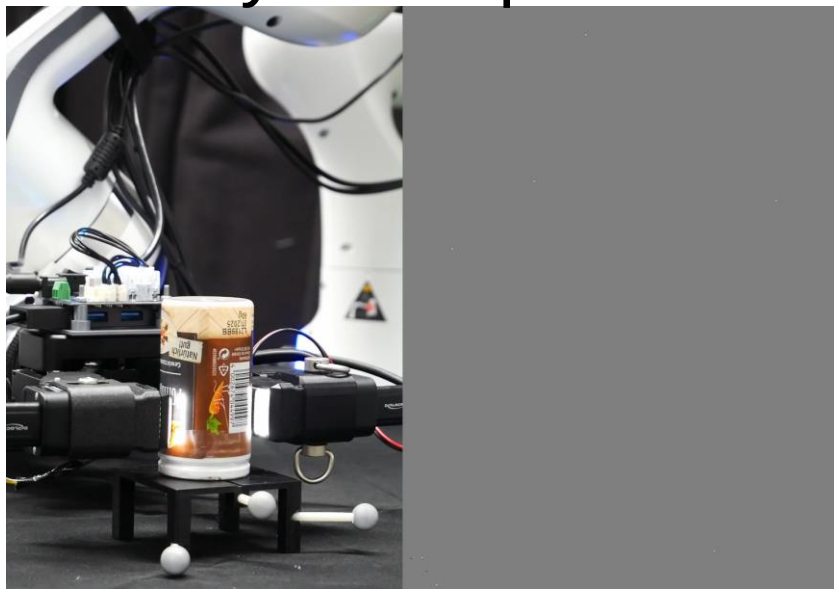


GRASP CONTROLLER GENERALIZATION

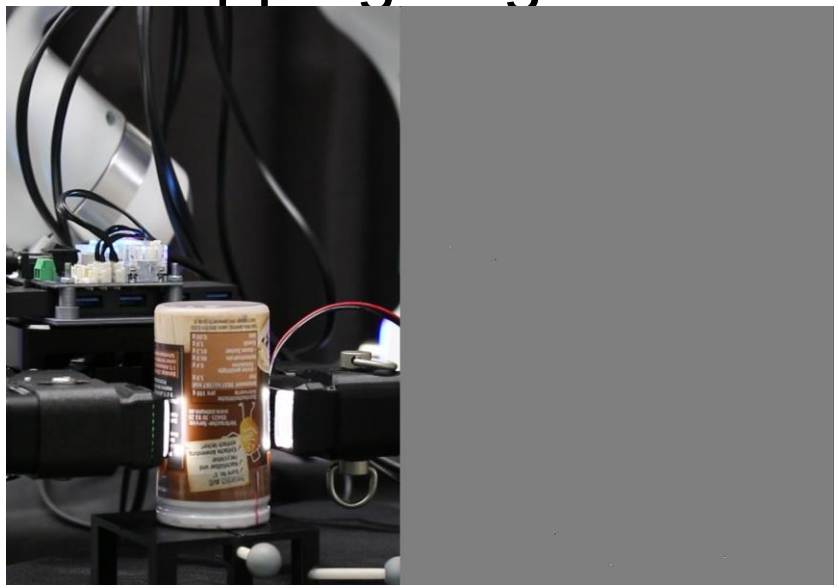


GRASP CONTROLLER ROBUSTNESS EVALUATION

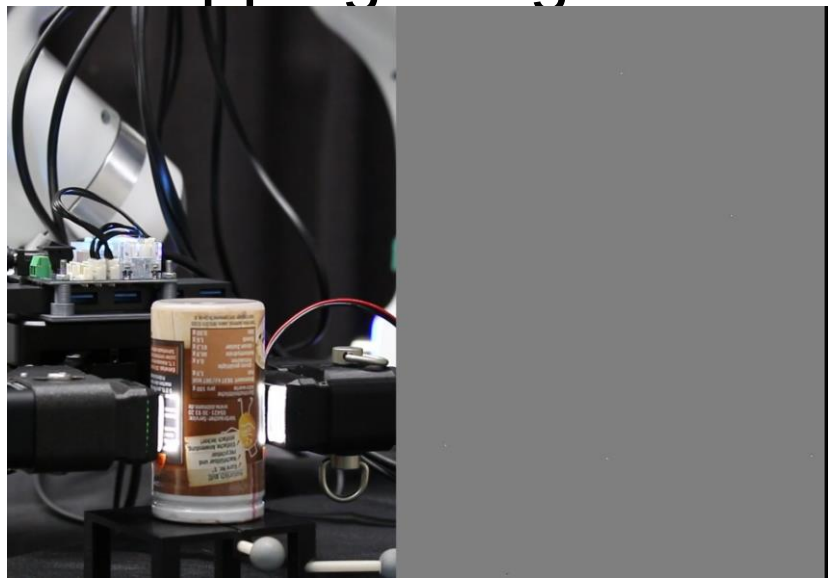
Sideways Grasp



Sideways Grasp & Dropping 20g



Sideways Grasp & Dropping 100g



INTERMEDIATE SUMMARY I

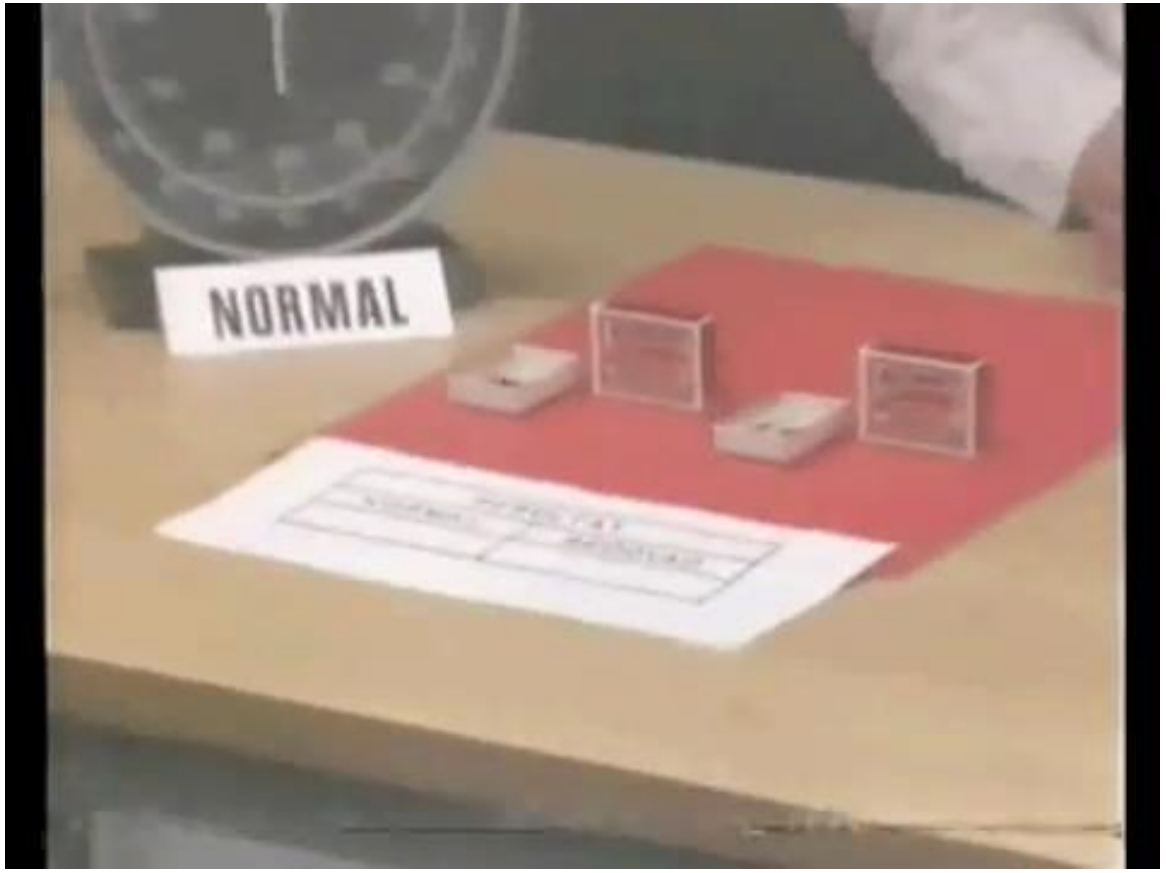
- Evetac: A new open-source event-based optical tactile sensor
- Sparse sensor output yields efficiency despite high readout rate
- Demonstrated generalizable slip detection & grasp control on household objects

Limitations:

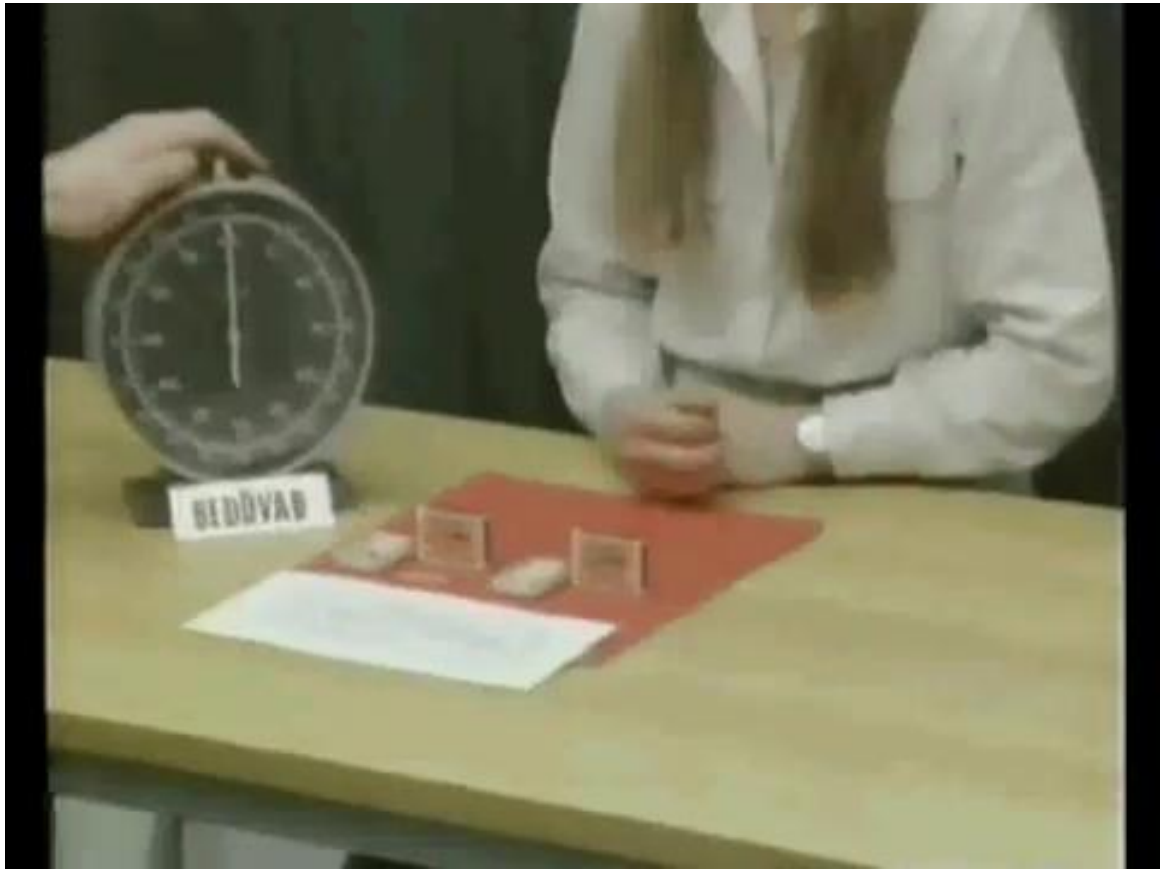
- Flat gel is limiting when interacting with more irregular objects
- Sensor size needs further improvement
- Focus on low-level grasping without adapting the robot‘s motion

Funk et al. “Evetac: An Event-based Optical Tactile Sensor for Robotic Manipulation", *T-RO 2024.*

IMPORTANCE OF TACTILE SENSING FOR HUMAN MANIPULATION



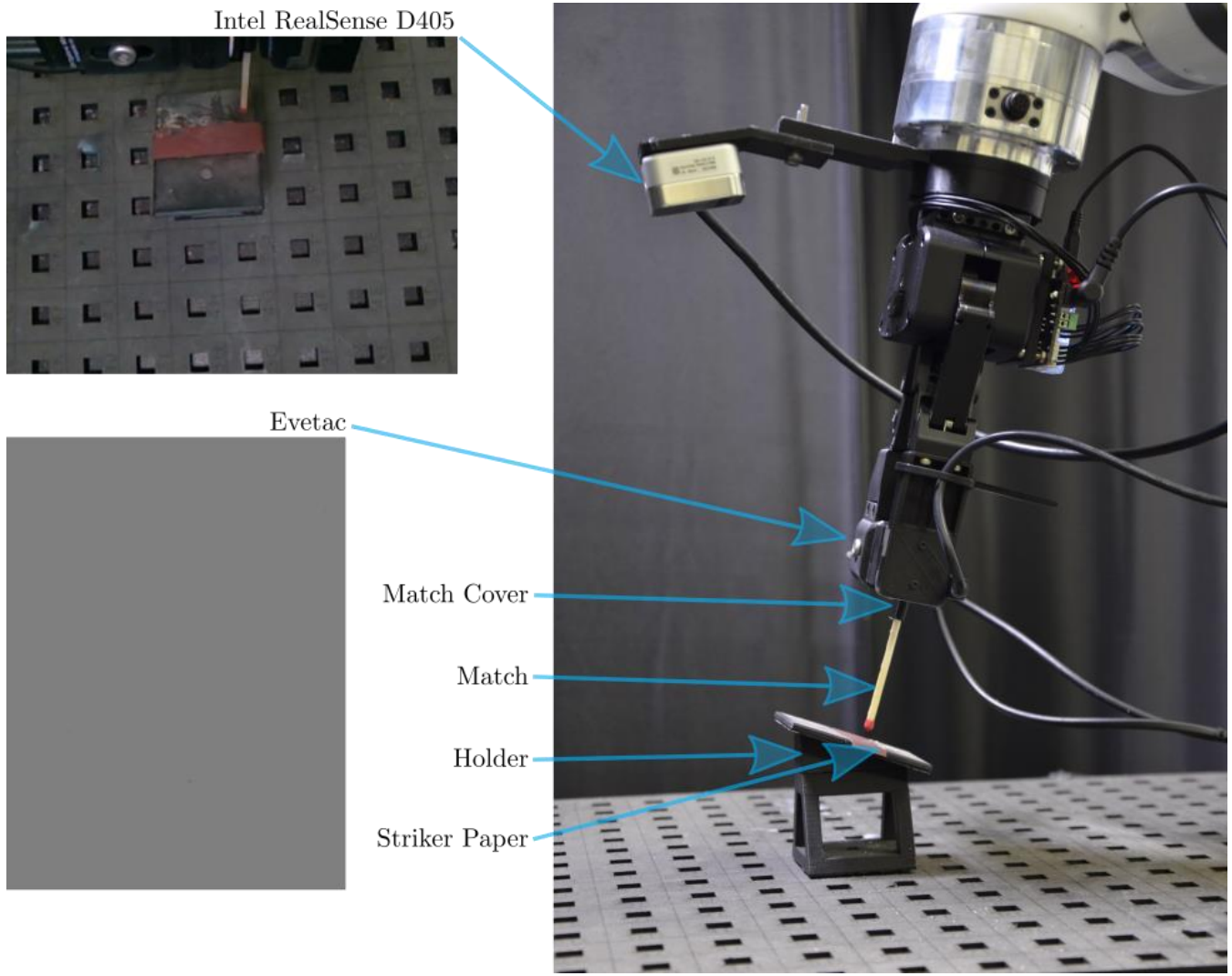
Normal, Pre-anesthetization Performance



Post-anesthetization Performance

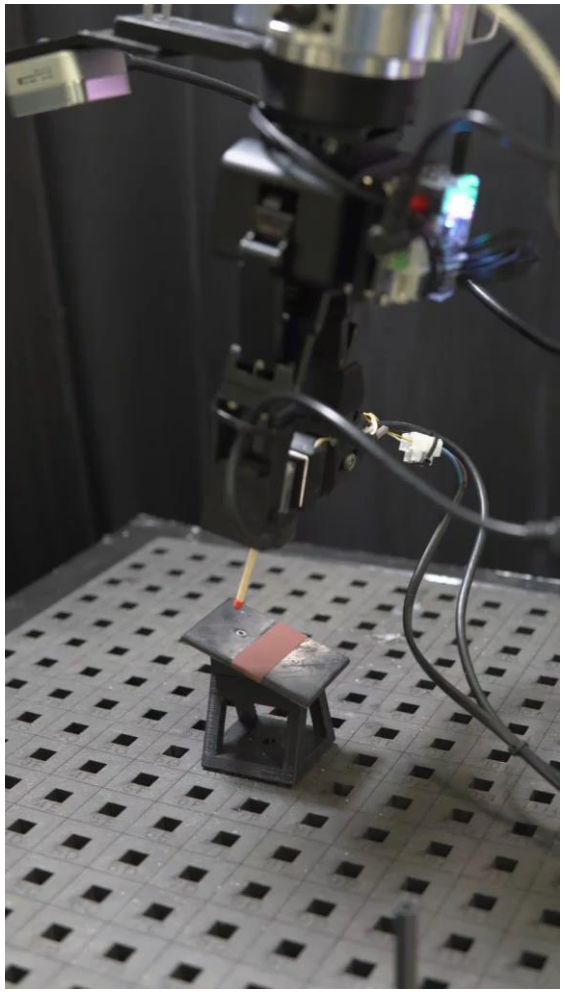
From the lab of Dr. Roland Johansson, Dept. of Physiology, University of Umea, Sweden
Source: https://www.youtube.com/watch?v=0LfJ3M3Kn80

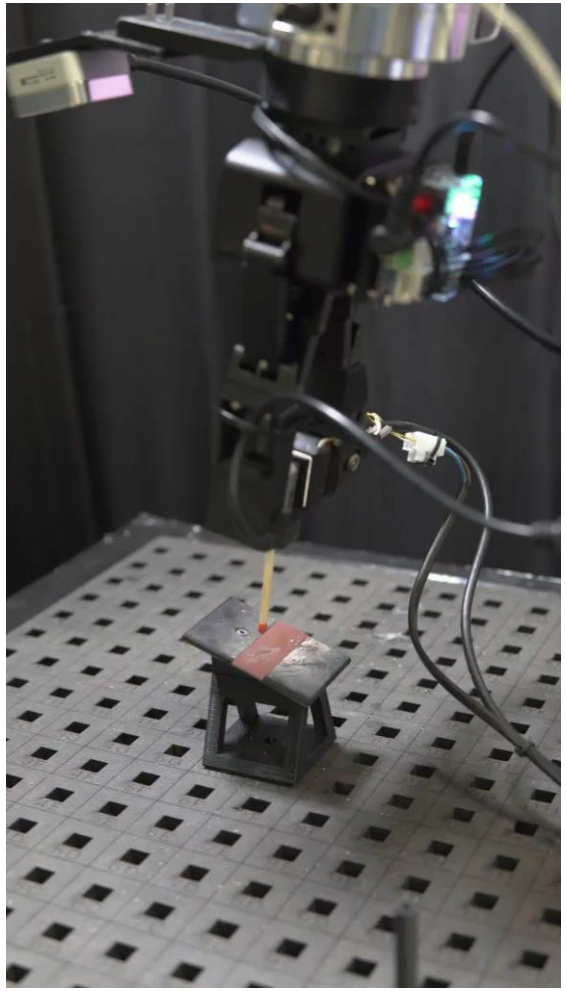
EXPERIMENT SETUP



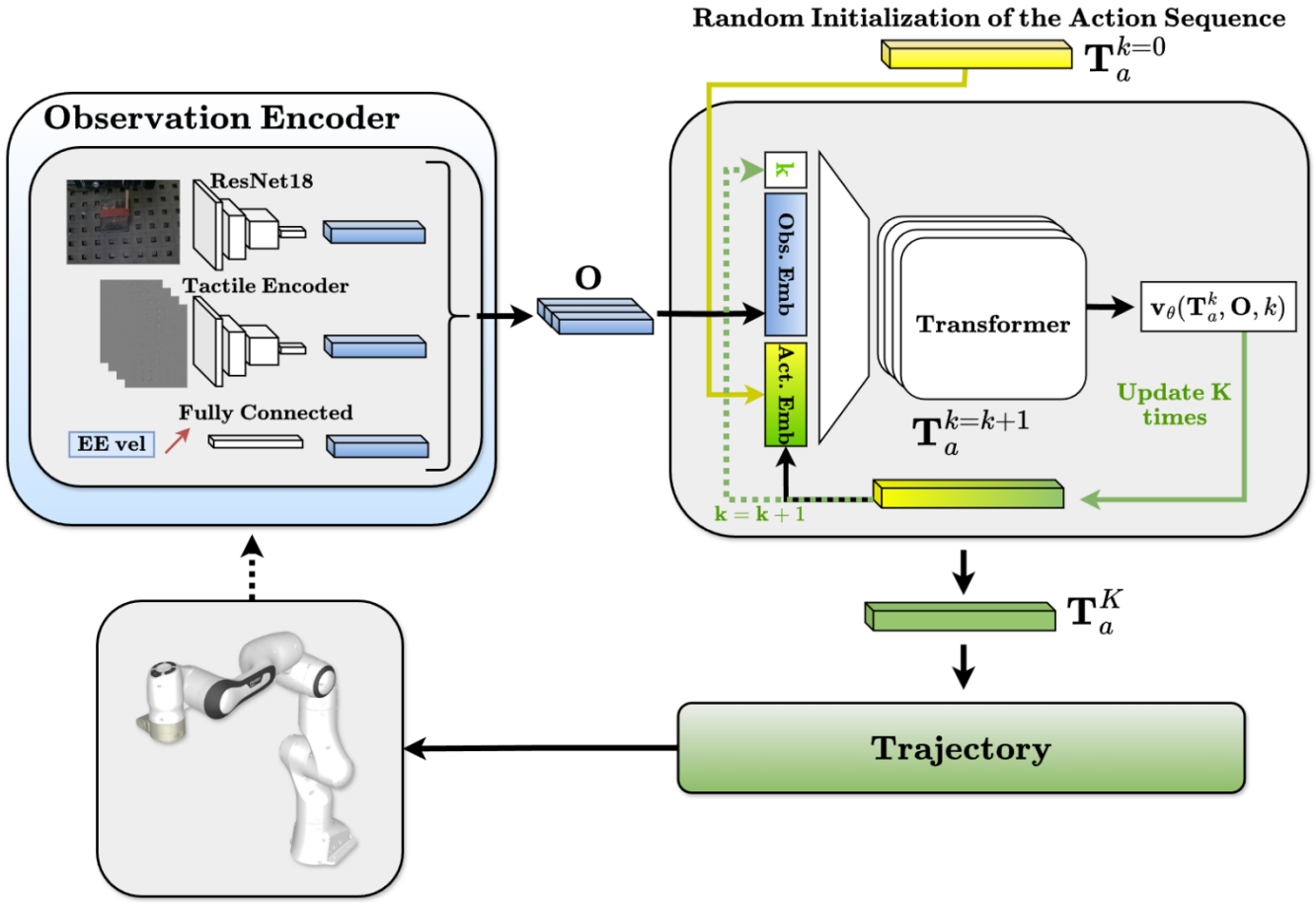
Funk et al. “On the Importance of Tactile Sensing for Imitation Learning: A Case Study on Robotic Match Lighting", *ViTac @ ICRA 2025.*

DATA COLLECTION PROCEDURE

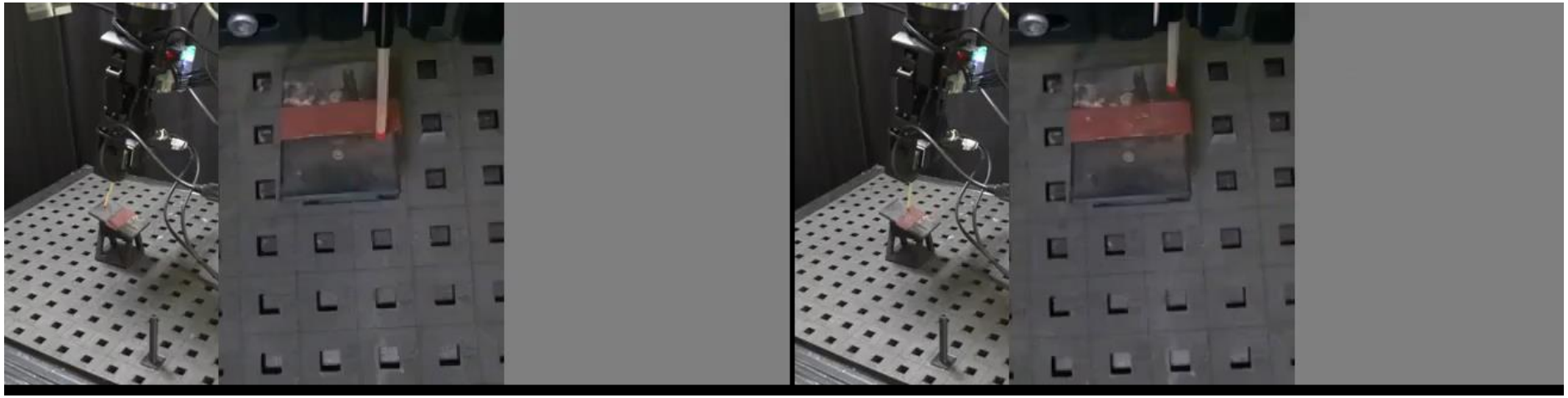




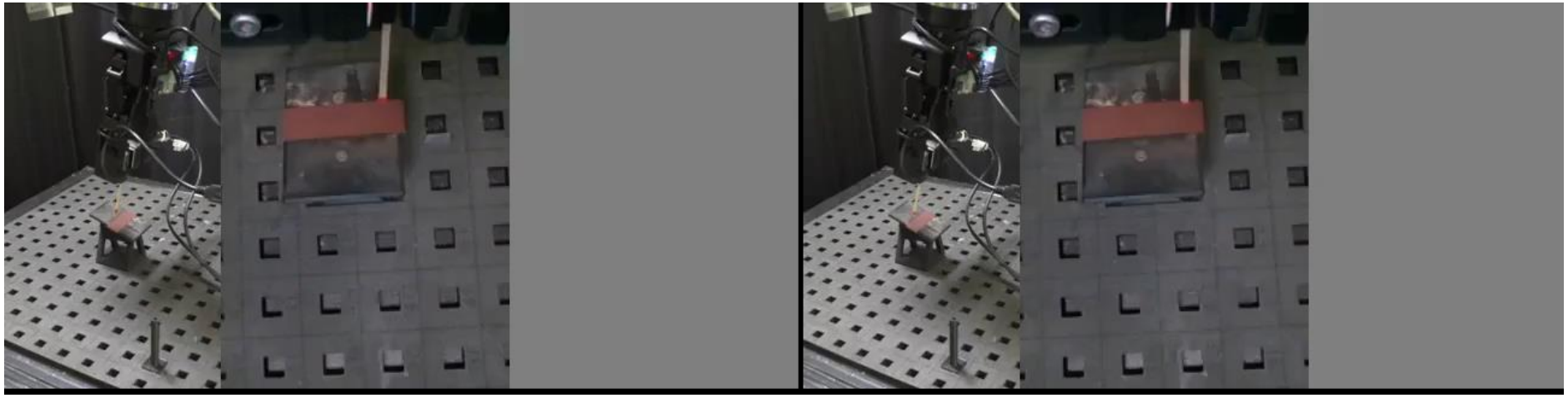
LEARNING MULTIMODAL POLICIES



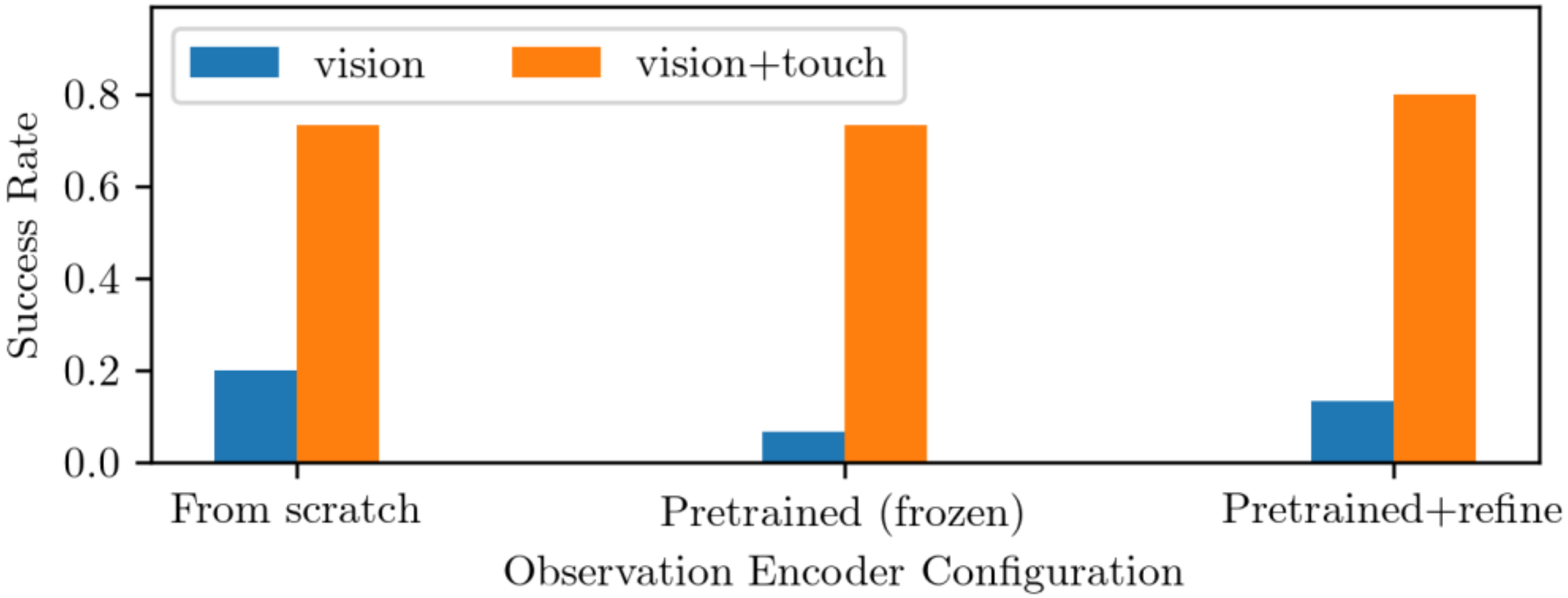
Vision + Touch (1x)



Vision only (1x)



QUANTITATIVE COMPARISON



INTERMEDIATE SUMMARY II

- Touch is a crucial sensing modality to obtain performant match lighting policies
- Findings hold across different observation encoding strategies

Limitations:

- Relies on collecting demonstrations using kinestethic teaching
- Policies limited to a single task

Funk et al. “On the Importance of Tactile Sensing for Imitation Learning: A Case Study on Robotic Match Lighting", *ViTac @ ICRA 2025.*

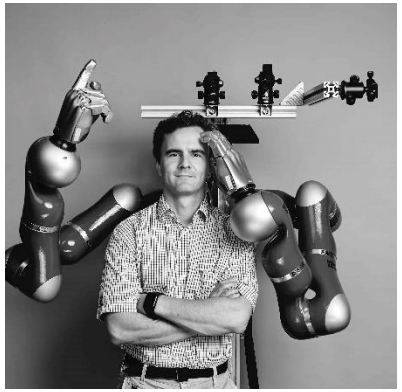
CONCLUSION

- Event-based optical sensing is promising as it enables high spatial & temporal resolutions, and sensing efficiency
- Touch is an important sensing modality for manipulation skill learning
- Importance of tactile sensing increases with task difficulty

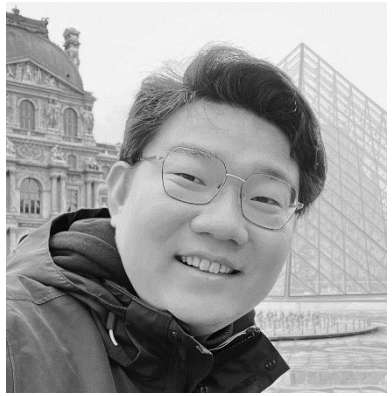
Future Work:

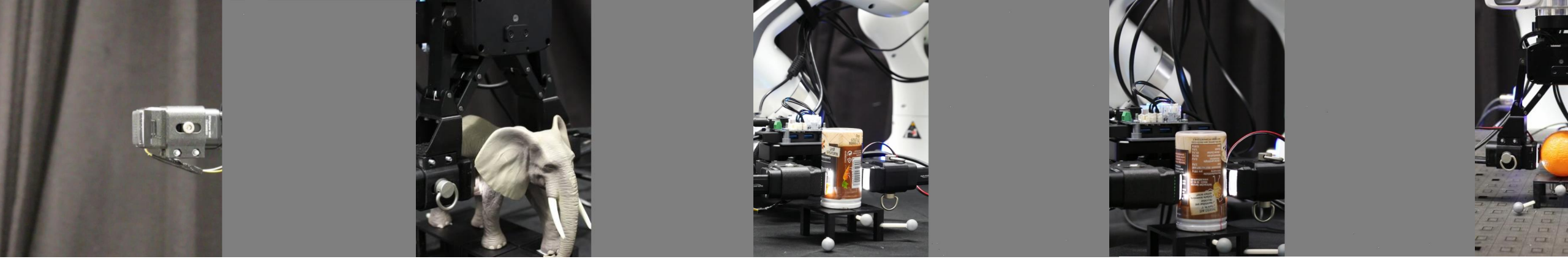
- Investigate the integration with event-based processing
- Integrate event-based tactile sensing on larger skin surfaces
- Research on multi-modal event-based sensing combining vision+touch

COLLABORATORS







EVENT-BASED OPTICAL TACTILE SENSING FOR ROBOTIC MANIPULATION

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