清華大學机械工程系
Department of Mechanical Engineering, Tsinghua University

自主机器人实验室
AUTOROBOT LABORATORY

Introduction of Personal Information and Research Experience

Name: Mingxuan Li

Department of Mechanical Engineering
Tsinghua University

Self Introduction

Name: Mingxuan Li **Background:** 1st-year master student, Tsinghua University

GPA: 3.9 / 4.0 (master); 3.7 / 4.0 (bachelor)

Major: Mechanical Engineering

Research Interests: Tactile Perception & Manipulation, Vision-Based Tactile Sensors, Computer Vision

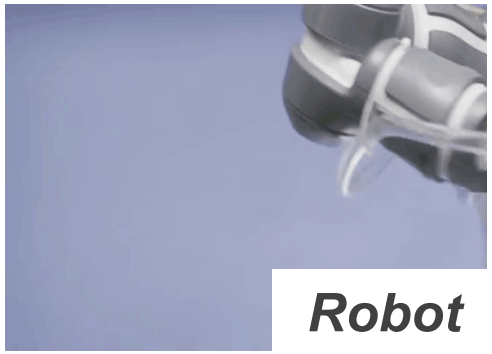
Selected Awards:

- Excellent Graduates (distinction) of Tsinghua University, 2023
- Comprehensive Outstanding Scholarship for several times
- Outstanding Graduation Thesis of Tsinghua University, 2023
- 2023 Person of the Year in the Department of Mechanical Engineering, Tsinghua University
- First Prize of Excellent Oral Presentation, The 734th Doctoral Academic Forum of Tsinghua University
- 1st Place in "New Engineering“ National Undergraduate Graduation Thesis Competition
- Best Poster and Excellent Oral Presentation Award, Tsinghua Youth Science and Innovation Forum
- Excellent academic paper, The 16th National Conference on Undergraduate Innovation
- Grand Prize of Outstanding Project of Tsinghua University Student Research Training Program
- “Spark” Innovative Talent Cultivation Program (Top 2% for outstanding research performance)

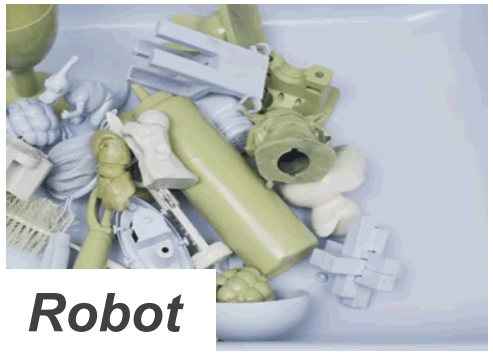
Dexterous In-Hand Manipulation


Human

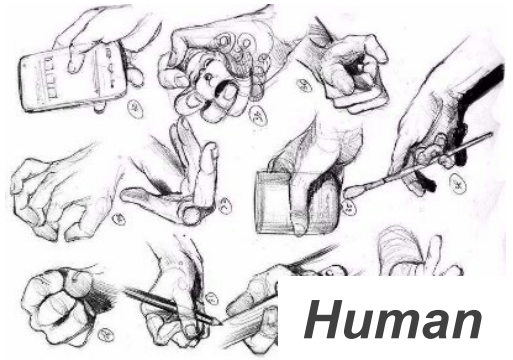
VS


Robot

Grasping Reliability

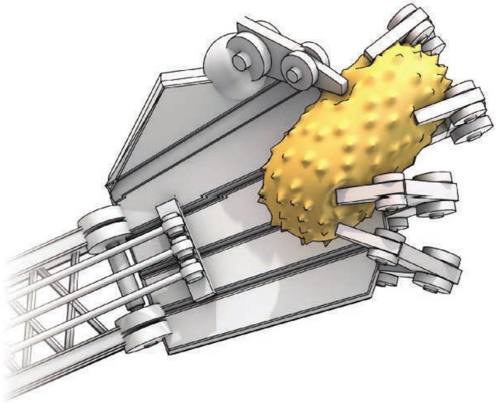

Robot

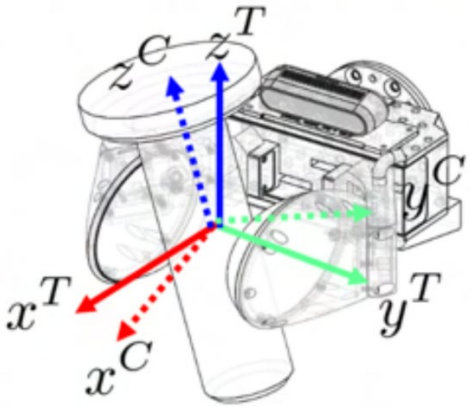
VS


Human

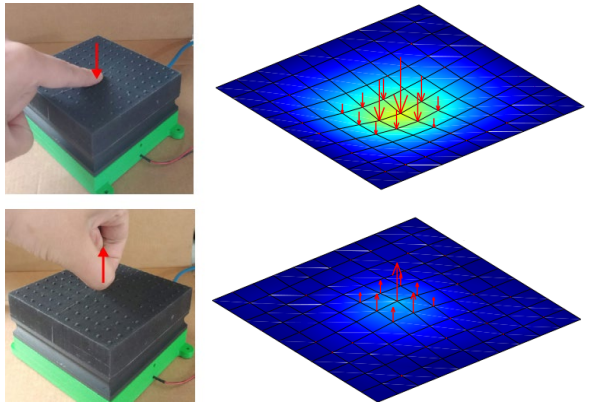
Manipulation Adaptability

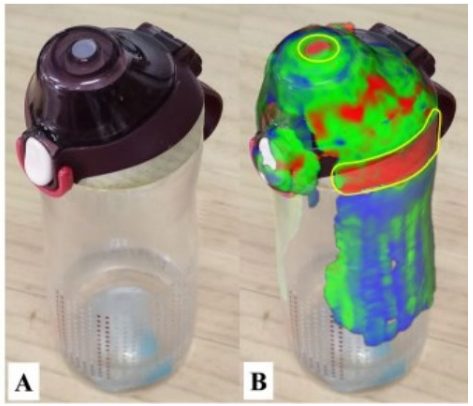
Tactile Sensing in Manipulation: Providing valuable **Contact Information**


Unknown contact



Object pose

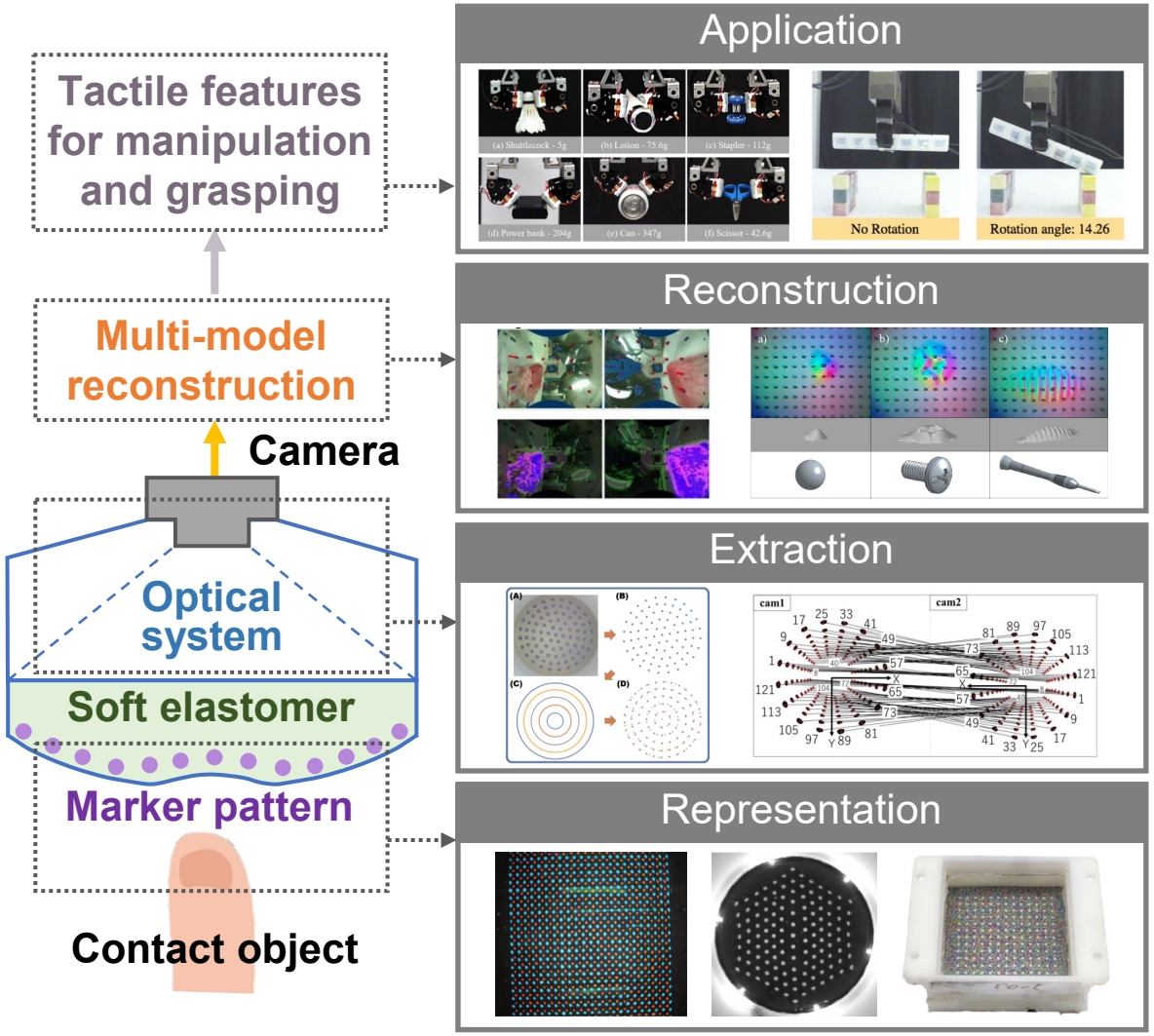

Contact force



Friction distribution

Reviewing Vision-based Tactile Sensing

- **Marker Displacement Method[1] in VBVS:**



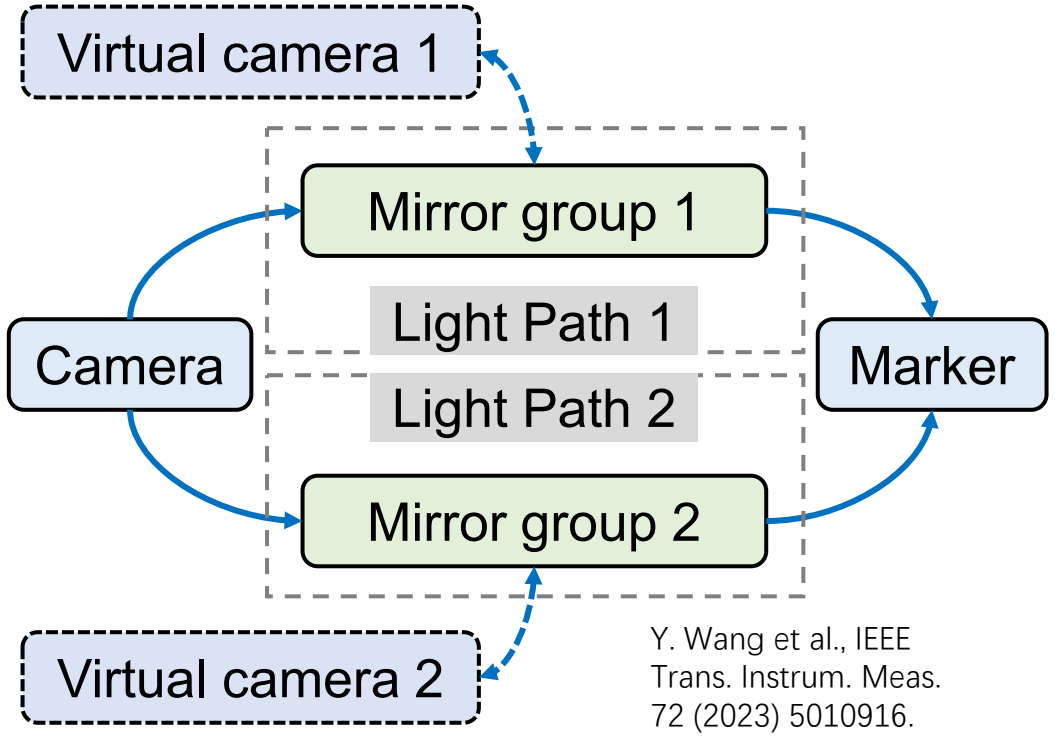
how to better utilize contact information?

How to better obtain contact information?

[1] Mingxuan. Li *et al.*, ***IEEE Sensors J.*** **(review article),** Apr. 2023, https://doi.org/10.1109/jsen.2023.3255861

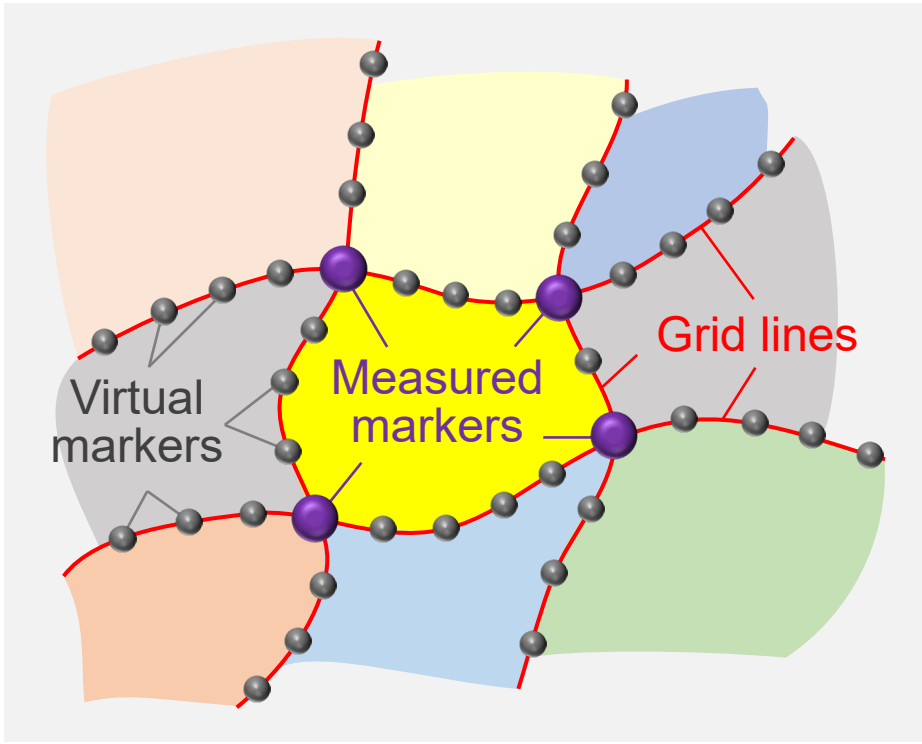
Contact Representation

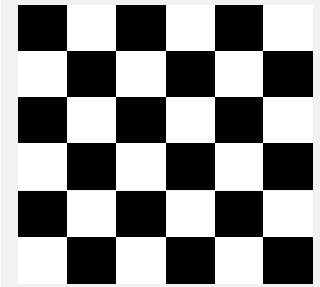
- **Virtual Binocular Vision:**



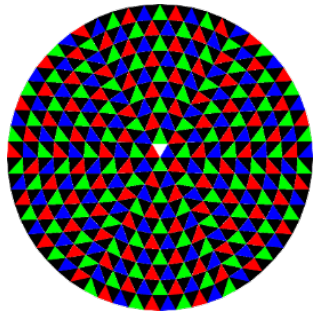
Y. Wang et al., IEEE Trans. Instrum. Meas. 72 (2023) 5010916.

- **Continuous Marker Pattern (CMP):**





Square CMP[2]



Multi-color CMP[3]

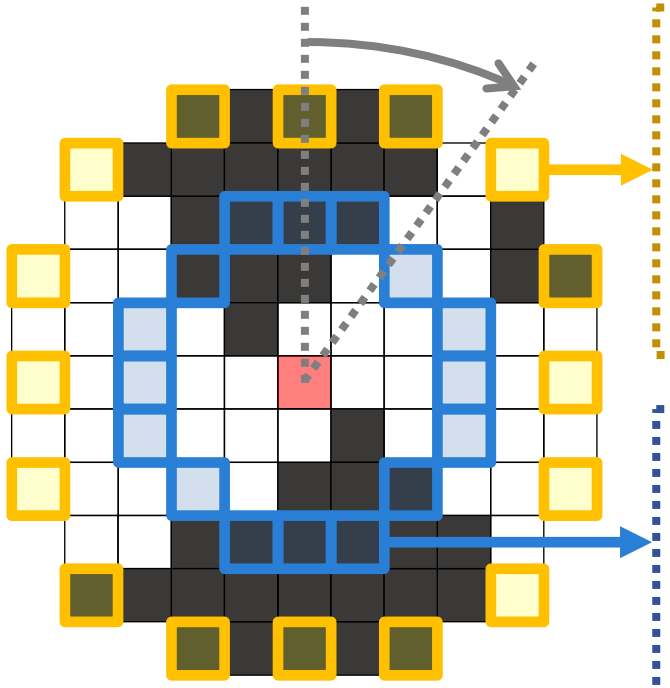
✓ **Only one camera** is needed to achieve **stereoscopic vision** (for synchronization and compactness)

✓ Discrete markers → continuous marker pattern: for **high precision, resolution, and reliability**

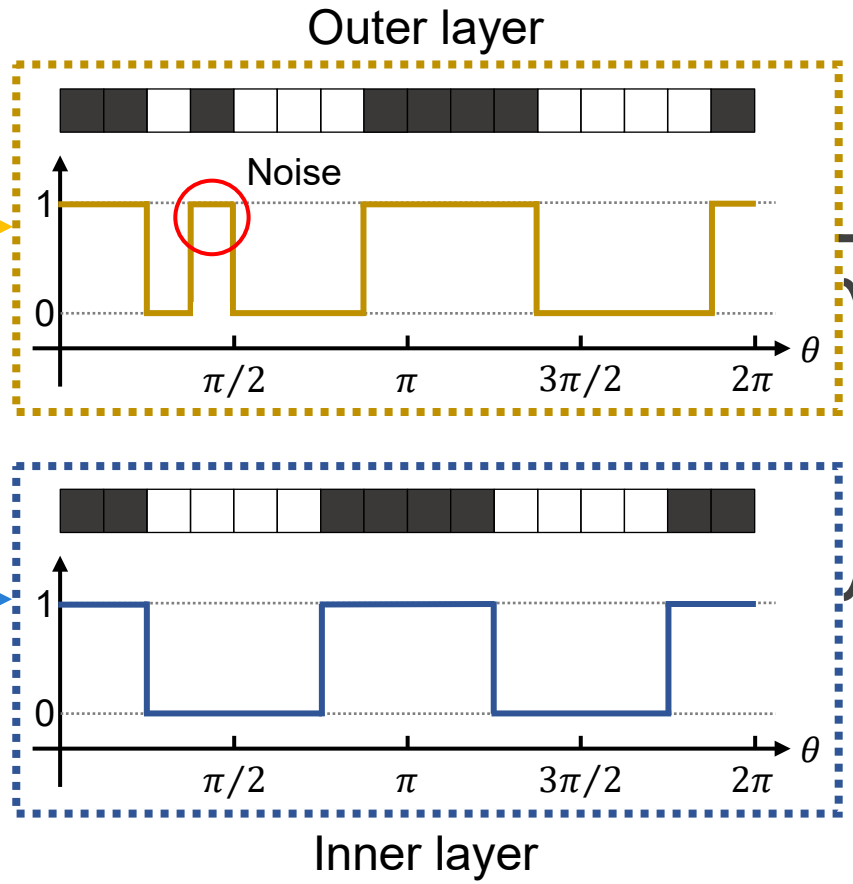
[2] Mingxuan. Li *et al.*, ***IEEE TIM***, Aug. 2022, https://doi.org/10.1109/tim.2022.3196730
[3] Mingxuan. Li *et al.*, ***IEEE RA-L***, Sep. 2023, https://doi.org/10.1109/lra.2023.3303830

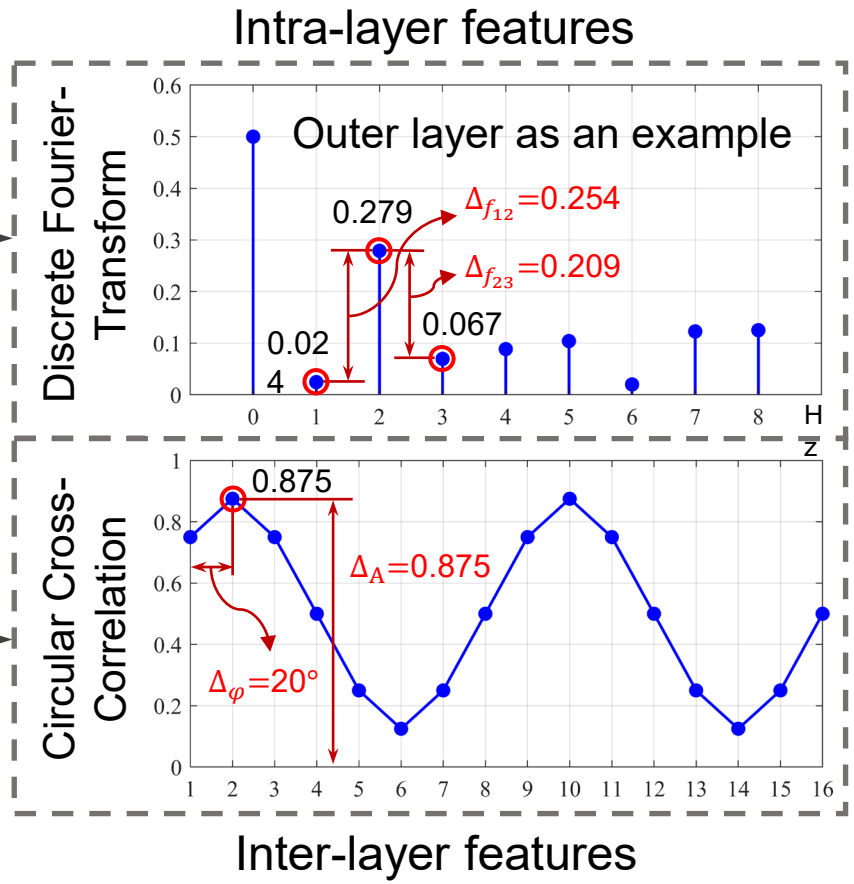
Contact Extraction

- **Marker Detection:**



[**Detector** of CMP]





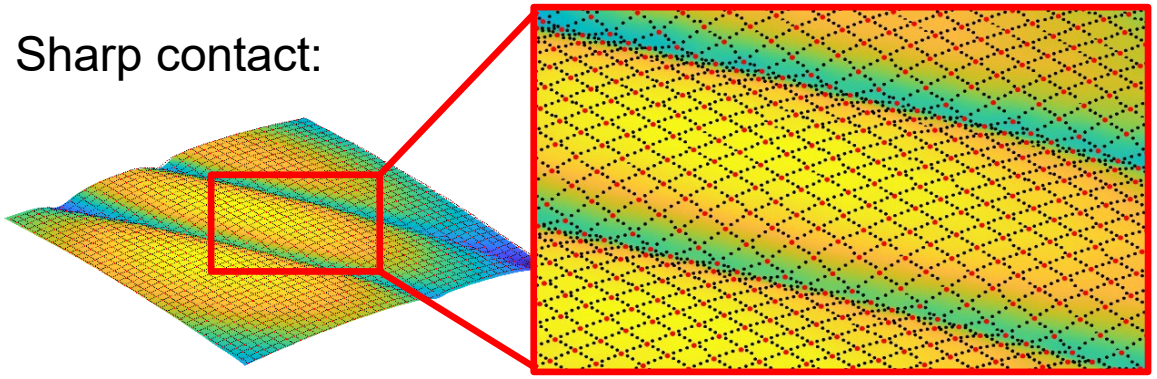
- ✓ **New sampler:** considering the influence of contact deformation on corner features (**distortion**)
- ✓ Selected features can preserve the true corners and filter out the **false candidate points**

[2] Mingxuan. Li *et al.*, ***IEEE TIM***, Aug. 2022, https://doi.org/10.1109/tim.2022.3196730
[4] Mingxuan. Li *et al.*, ***Measurement***, Nov. 2023, https://doi.org/10.1016/j.measurement.2023.113479

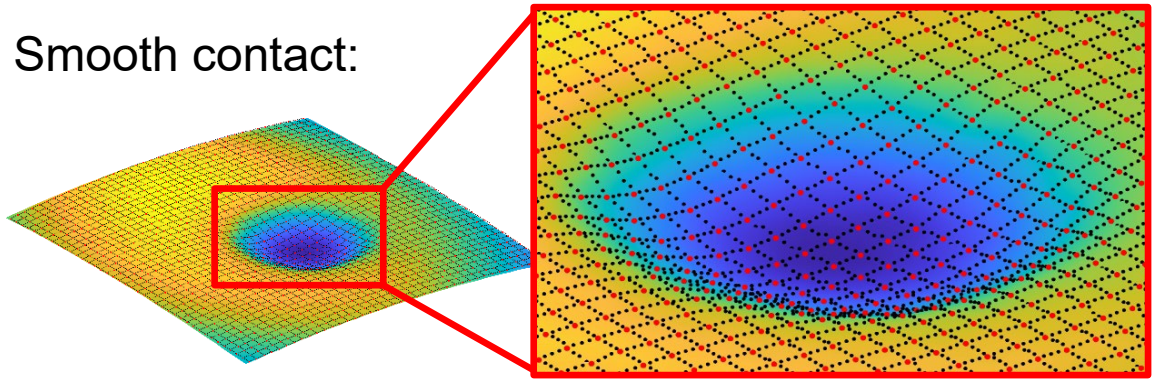
Contact Reconstruction

- **Deformation Reconstruction:**

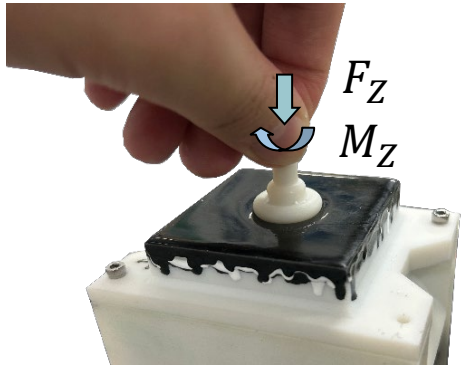
Sharp contact:

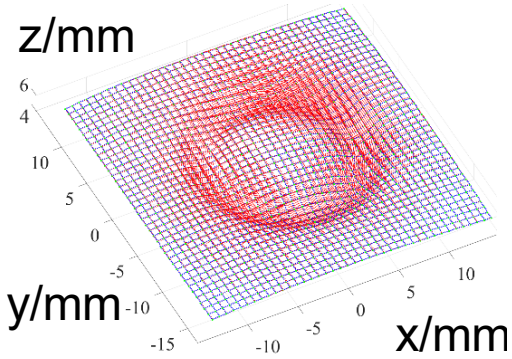


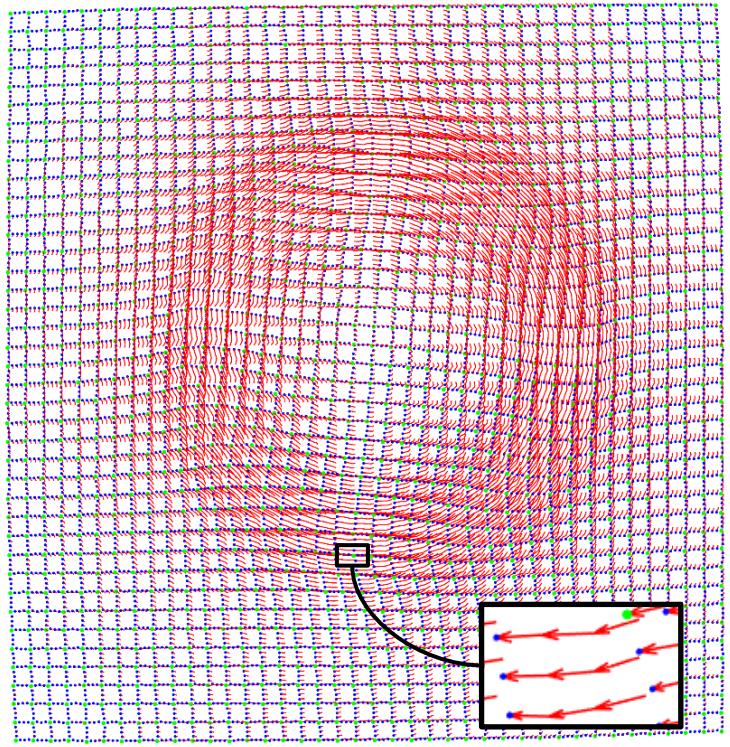
Smooth contact:



- **Motion Tracking:**





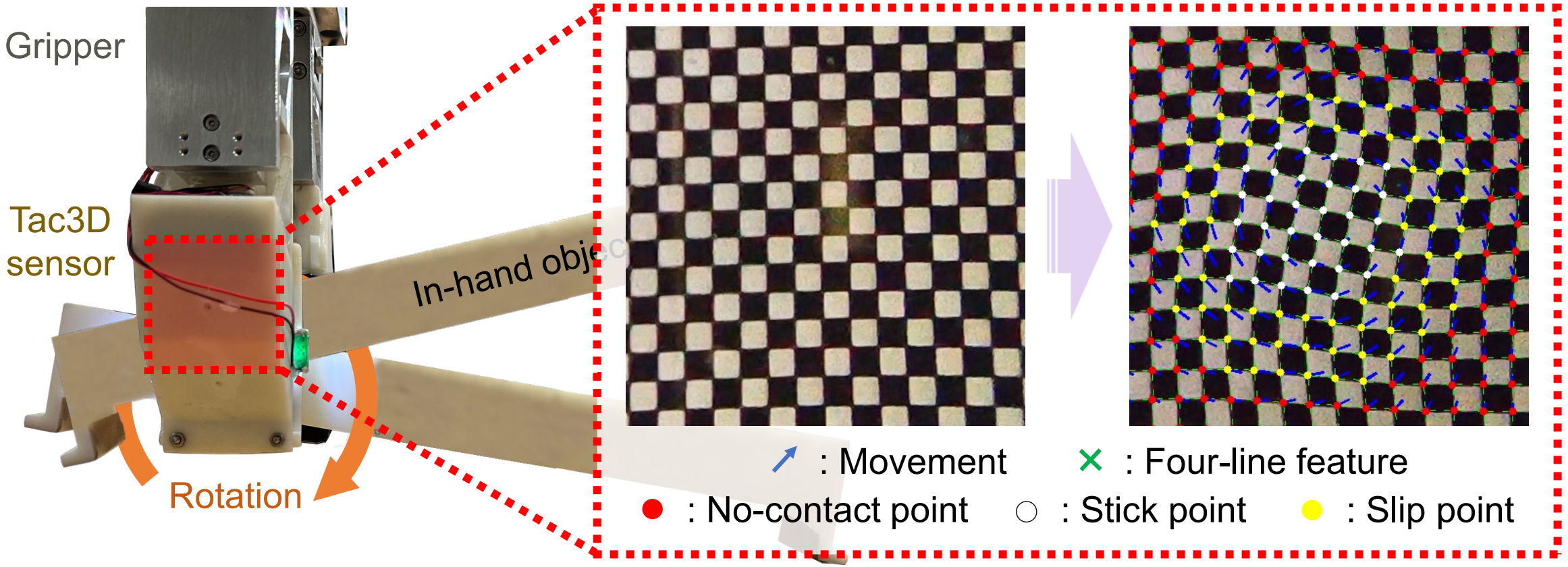


✓ **3-D Deformation Reconstruction:** Improving the real-time performance and robustness (execution speed: 120Hz, success rate: 97.5%) to achieve high density.

[4] Mingxuan. Li *et al.*, ***Measurement***, Nov. 2023, https://doi.org/10.1016/j.measurement.2023.113479

Application: Rotation Measurement

- **Pivoting Rotation Measurement:**



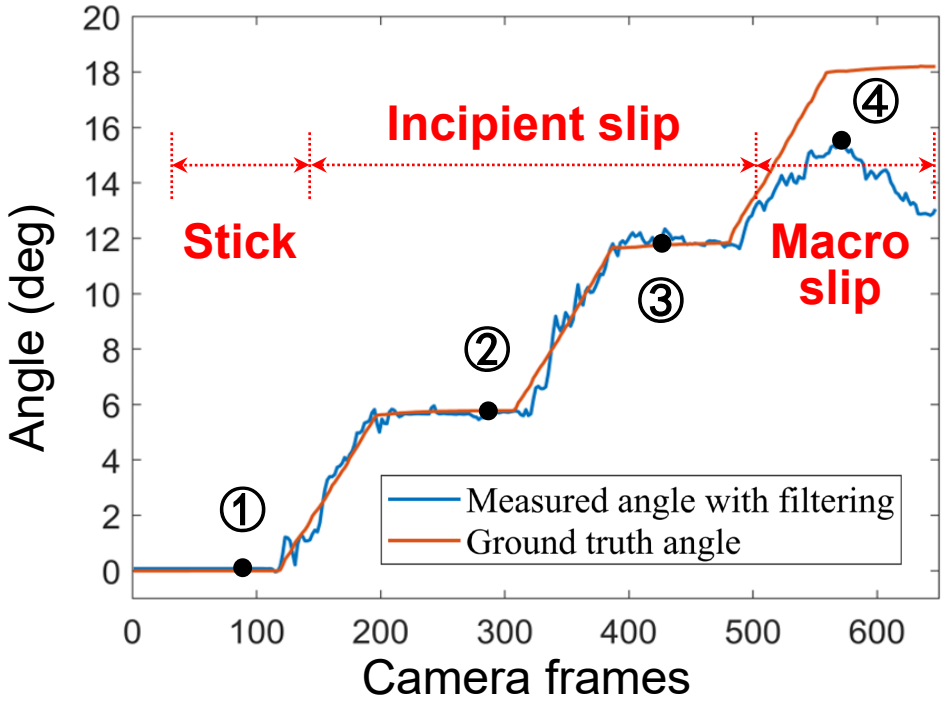
✓ **Ensuring Accuracy:** Exclude the slip markers and utilize only the **stick region** for the calculation

✓ **Mean absolute rotational error:** $\mathbf{0.17° \pm 0.15°}$ (SOTA) [Baseline: MARE of $\mathbf{3.09° \pm 2.92}$].

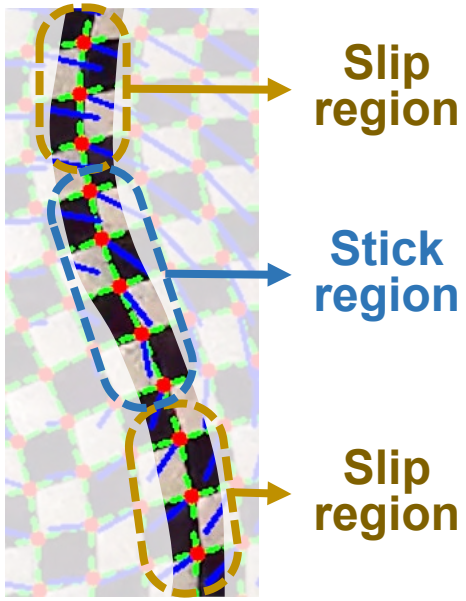
[5] Mingxuan. Li *et al.*, ***2024 ICRA***, https://arxiv.org/abs/2309.05366

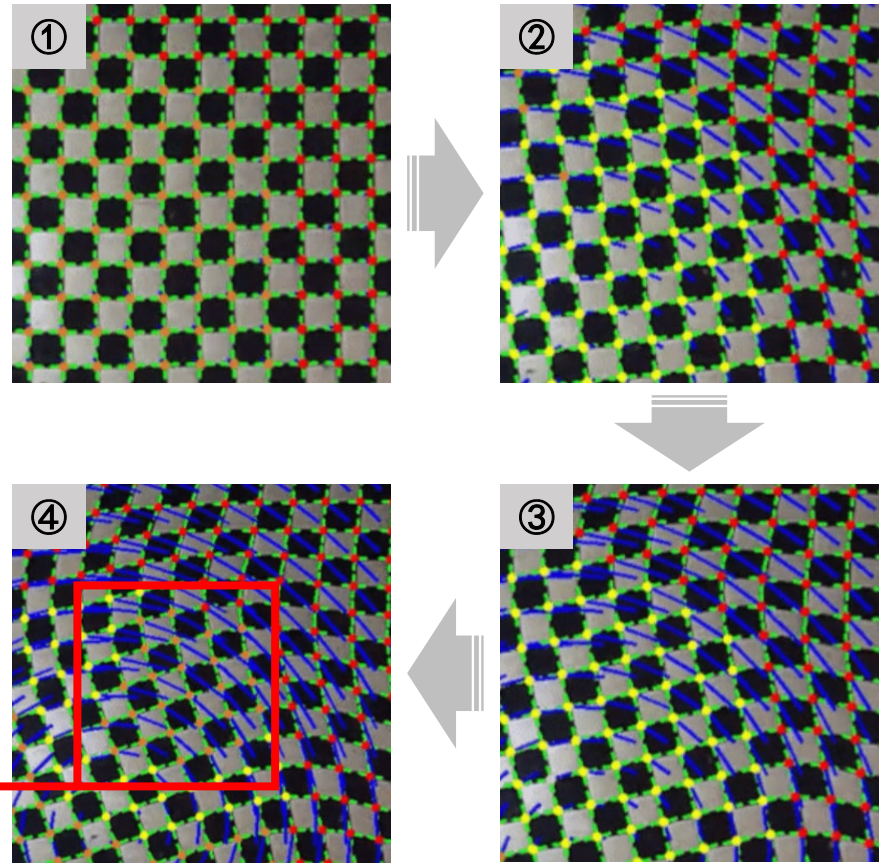
Application: Rotation Measurement

- **Pivoting Rotation Measurement:**



Measured angle vs Ground truth





✓ **Ensuring Accuracy:** Exclude the slip markers and utilize only the **stick region** for the calculation

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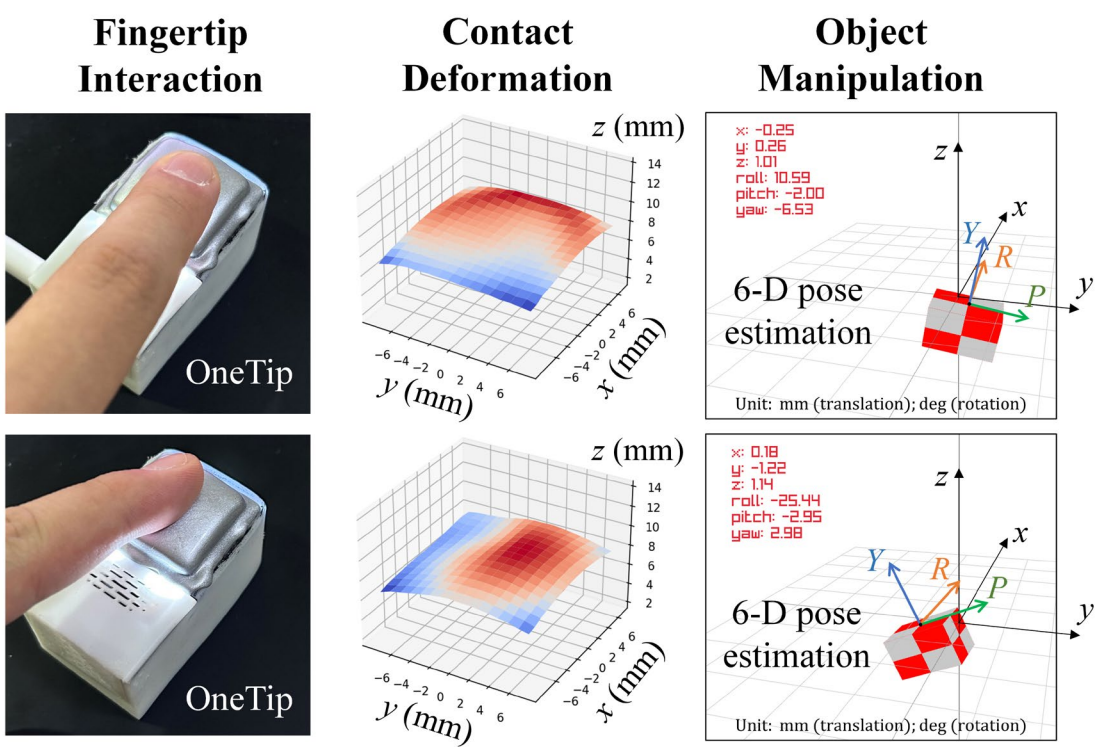
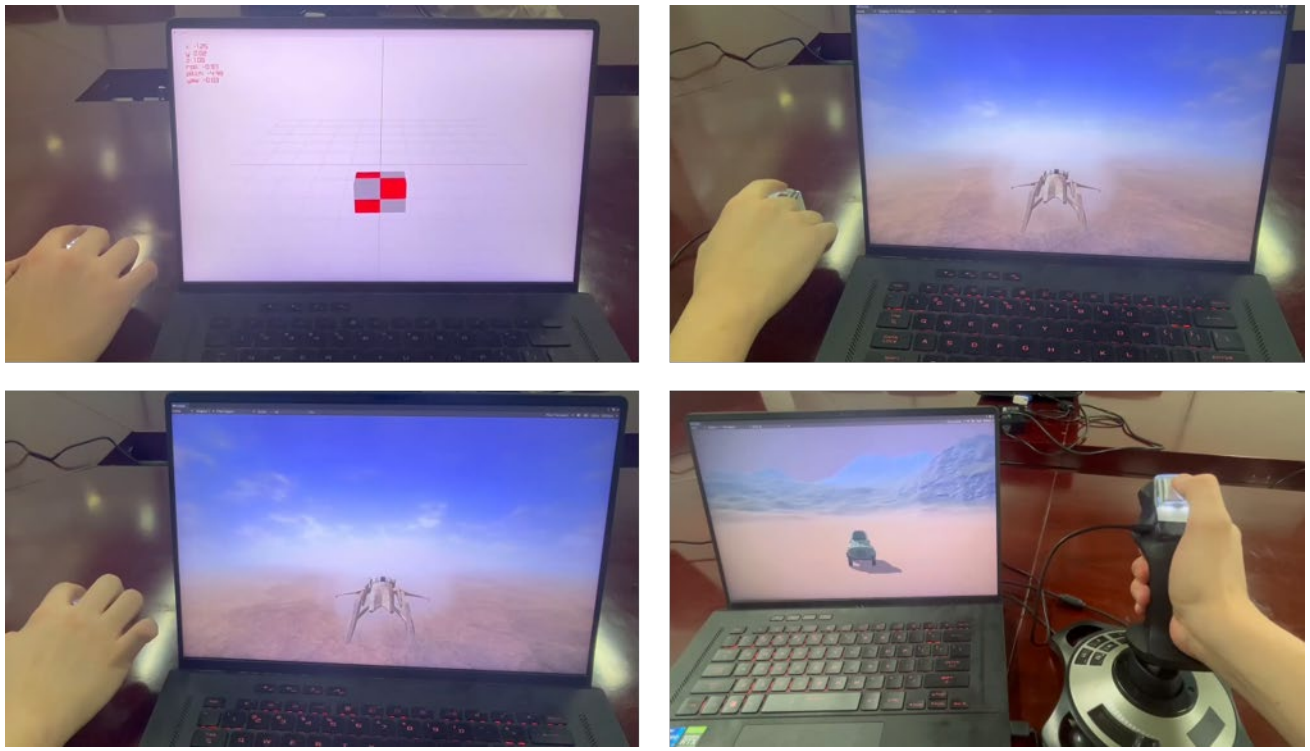
[5] Mingxuan. Li *et al.*, ***2024 ICRA***, https://arxiv.org/abs/2309.05366

Application: Human-Computer Interaction

- **Interaction Paradigm:**



- **Application in HCI:**



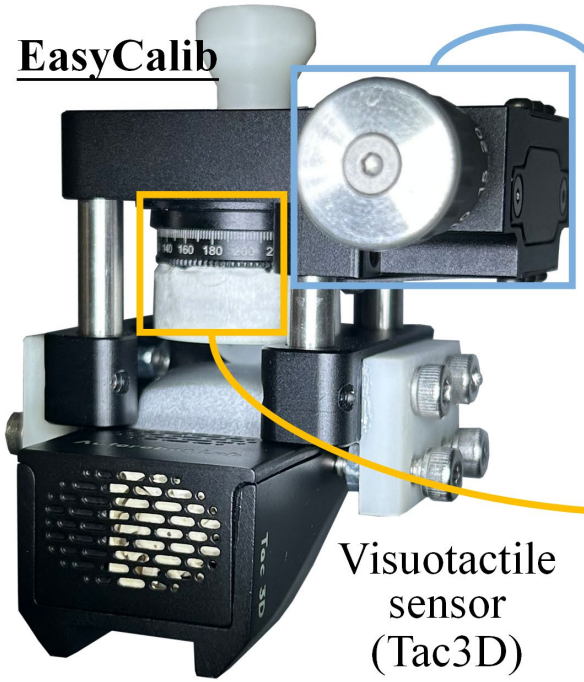
✓ **Fingertip Pose Estimation:** **Incipient slip detection** method that can be applied for **soft object**

✓ **OneTip:** A non-rigid **tactile interface** for single-fingertip human-computer interaction with 6 DOFs

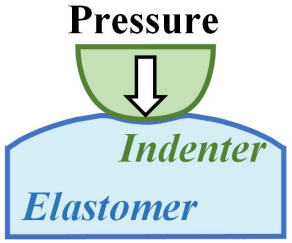
[6] Mingxuan. Li *et al.*, ***Sensors and Actuators: A. Physical***, in revision, https://doi.org/10.36227/techrxiv.170775314.44150885/v2

Application: Force Reconstruction

- **Calibration of Mechanical Parameters:**



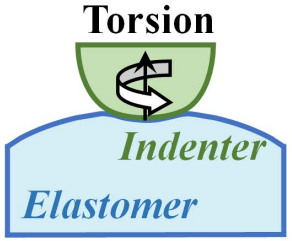
Calibration based on **Normal Contact Theory**



$$\gamma_2 = \boldsymbol{H_1} \cdot \gamma_1 + H_2 \cdot {\gamma_1}^{1.5},$$

$$\boldsymbol{H_1} = \frac{32}{9\pi} \cdot \frac{1 - {\nu_2}^2}{1 - {\nu_1}^2} \cdot \frac{E_1}{E_2}$$

Calibration based on **Torsion Contact Theory**



$$\theta_2 = \boldsymbol{H_3} \cdot \theta_1,$$

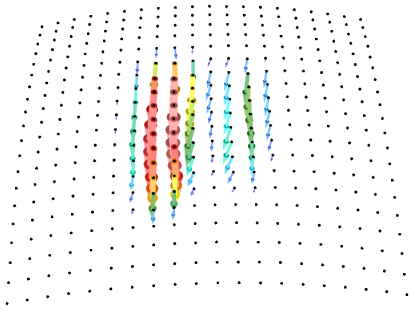
$$\boldsymbol{H_3} = 2.014 \cdot \frac{1 + \gamma_2}{1 + \gamma_1} \cdot \frac{E_1}{E_2}$$

Calculating the mechanical parameters of elastomers

- Young's modulus $\boldsymbol{E}$
- Poisson's ratio $\boldsymbol{\nu}$

Inverse finite element method

Contact object



Force reconstruction

✓ **EasyCalib:** In-situ calibration that relied on **comparing contact deformation** (without F/T sensors)

✓ **Deformation-based:** Constructing the relationship of deformation field based on **contact modeling**

[7] Mingxuan. Li *et al.*, ***IEEE RA-L***, Jul. 2024, https://doi.org/10.1109/lra.2024.3426383

Thank You Very Much