HOT CHIPS

Hot Chips 33, August 24, 2021

# New Value Creation by Nano-Tactile Sensor Chip Exceeding our Fingertip Discrimination Ability


香川大学 KAGAWA UNIVERSITY

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岡山県立大学 OKAYAMA PREFECTURAL UNIVERSITY

Kazutami ARIMOTO
Okayama Prefectural University, JAPAN

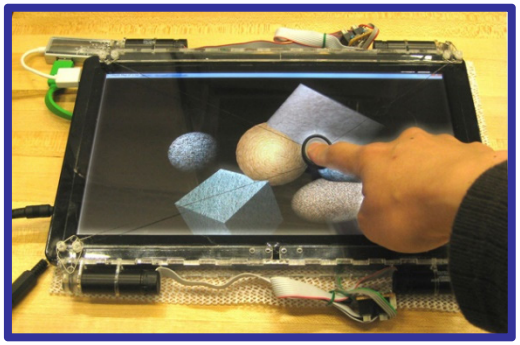
# Texture Discrimination and Quantification

New Value Creation in Future Applications

Quality Control

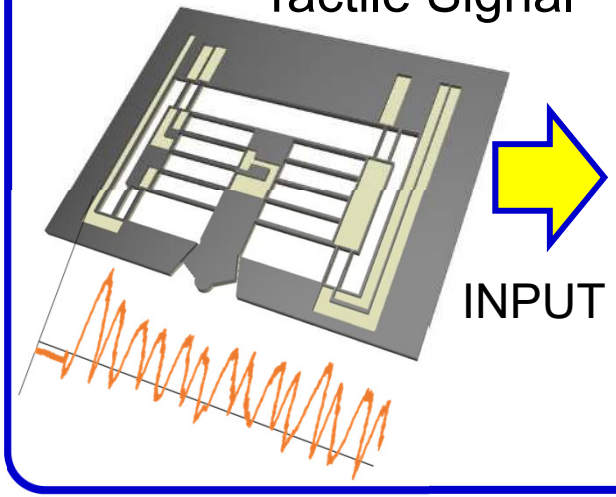
Health Care

Remote Treatment



H/M Interface

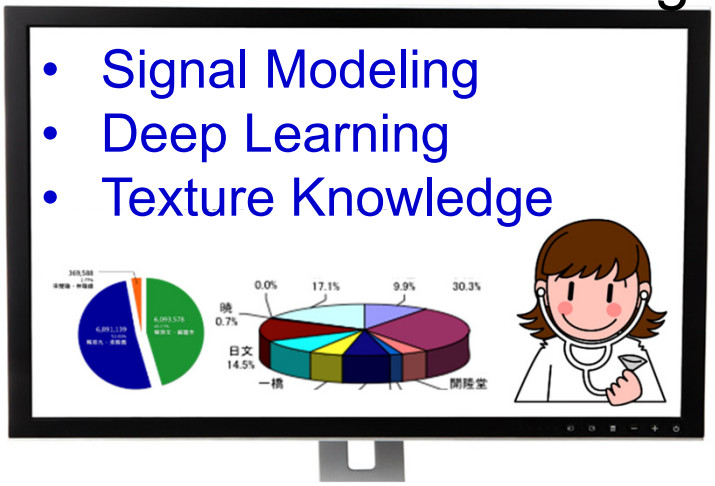
High-Resolution Tactile Signal



INPUT

Information Processing

- Signal Modeling
- Deep Learning
- Texture Knowledge



Exceeds Human's Sense of Touch?

CREST
戦略的創造研究推進事業
Core Research for Evolutionary Science and Technology

(2015-2021)
(2020-2026)

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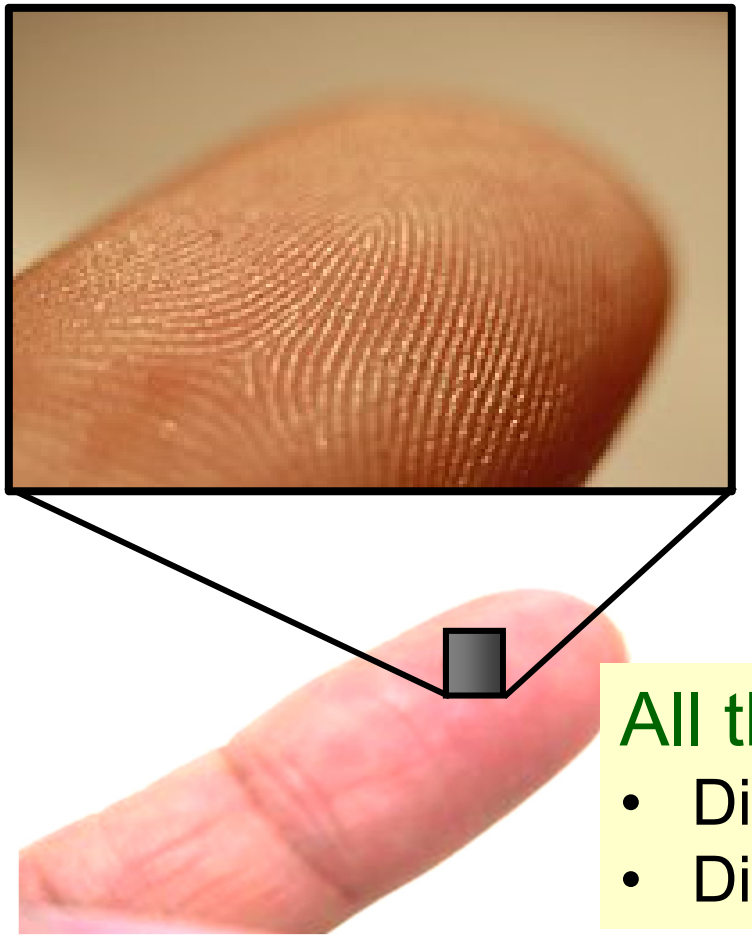
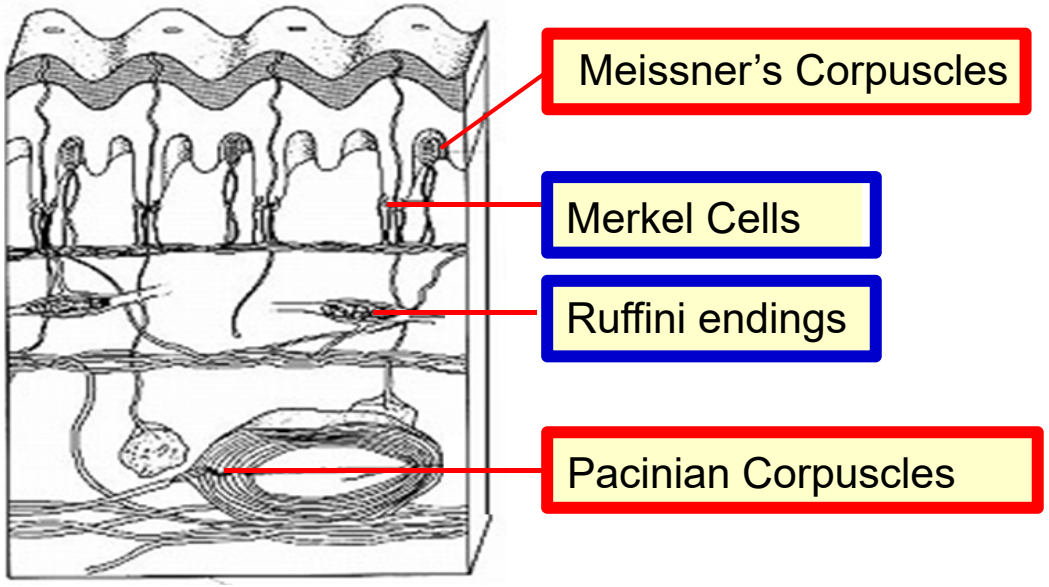
# Our Sense of Touch

## Distributed Receptors under the Elastic Skin Structure



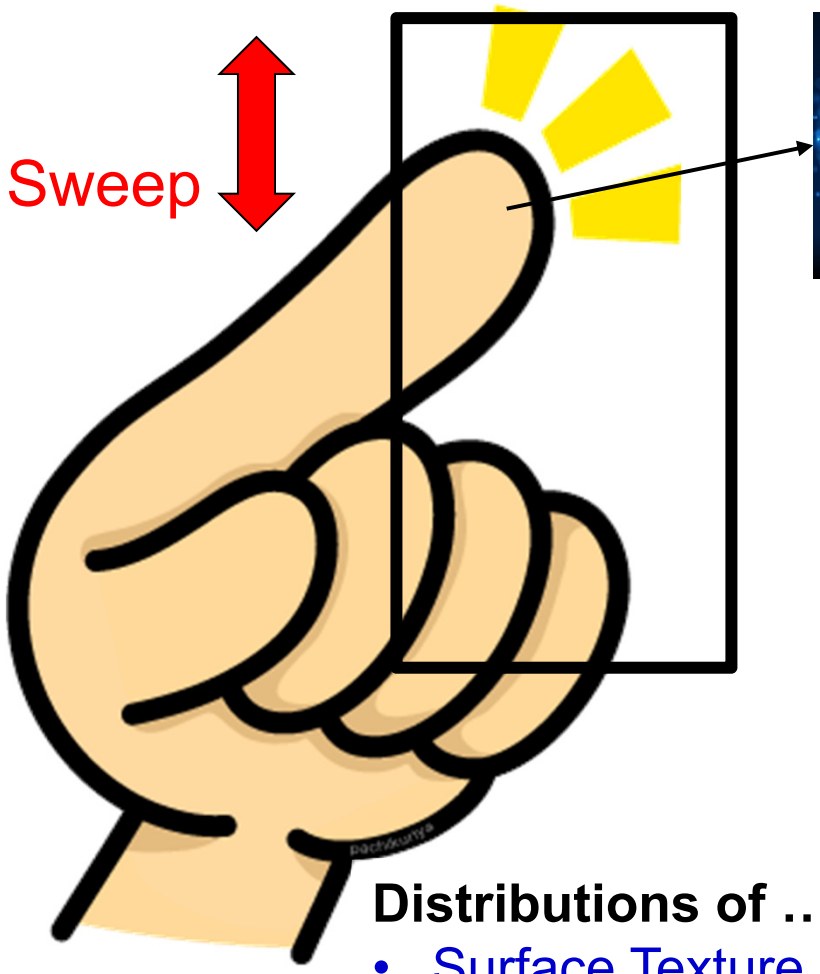


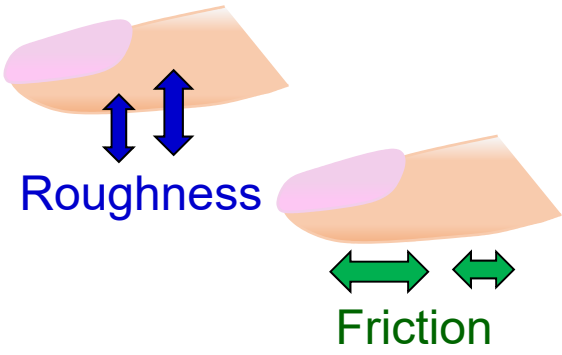

Corpuscles in Fingertip Skin
(Darian-Smith. 1984)

All the Nerve Cells Sense "Vibration"

- Different Depth (Spatial Resolution)
- Different Speed of Response

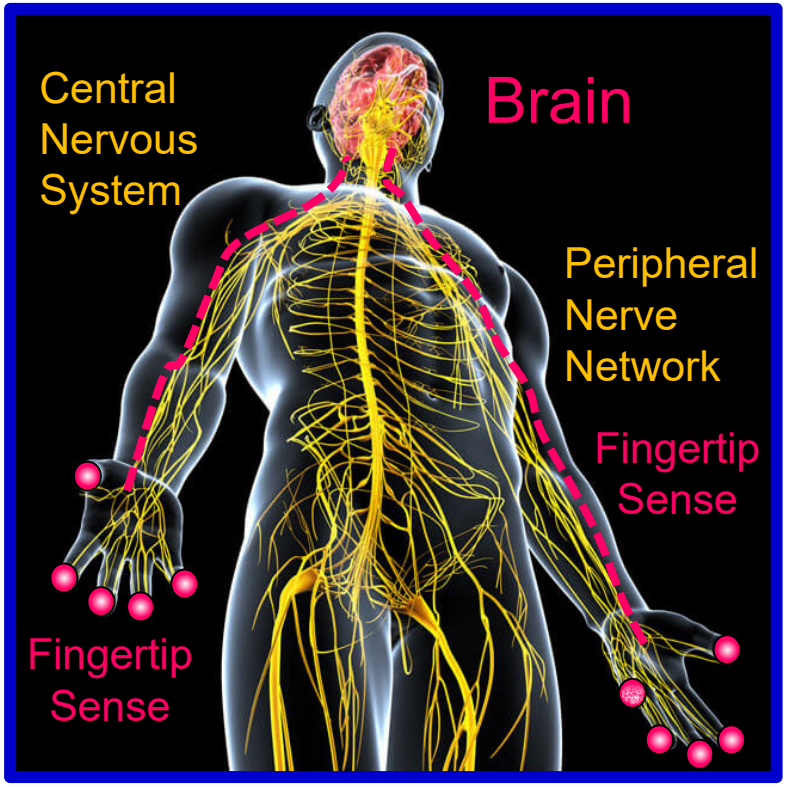
# How Do We Feel the Surface Texture?



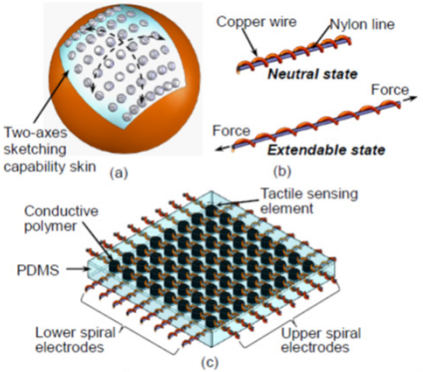

**Distributions of …..**

- Surface Texture
- Frictional Force
- Hardness

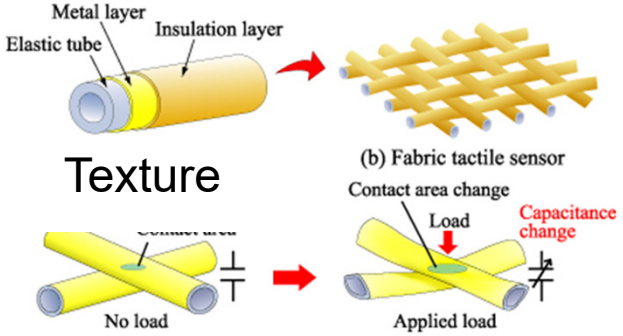


# Tactile Sensors at Present

- **Flexible Sensors (ex. Organic Semiconductors) for Wide Area Body Skin**

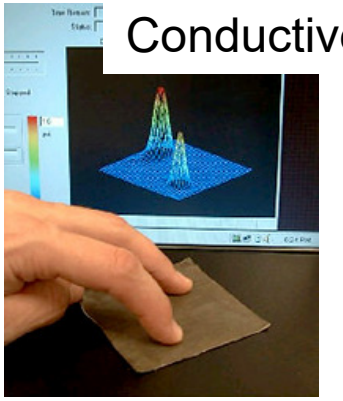



M. Cheng, Y. Yang et al.
National Taiwan Univ., Taiwan




M. Shikida, K. Sato et al.
Nagoya University, Japan

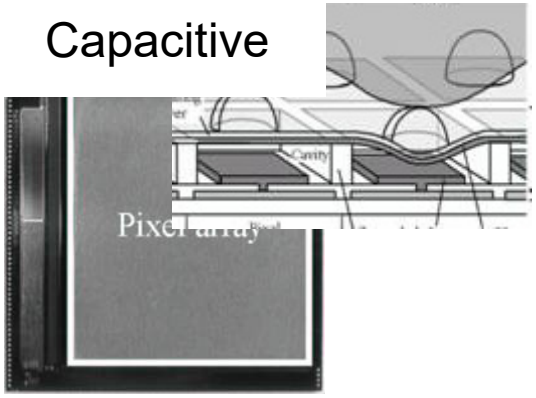
Conductive Rubber



Pressure Profile Systems Inc.,
U.S.A

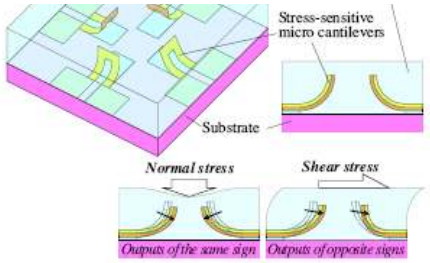
- **Silicon-MEMS Sensors for Fingertip Like Sensation**

Capacitive



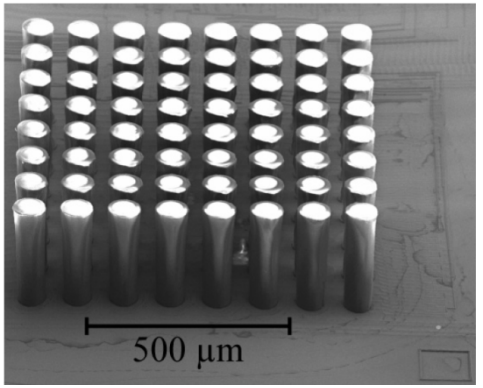

N. Sato, K. Machida et al.
NTT Corporation, Japan

Metal Strain-gauge




M. Sohgawa, M Noda et al.
Osaka University, Japan
Kyoto Institute of Tech., Japan

Piezoresistive



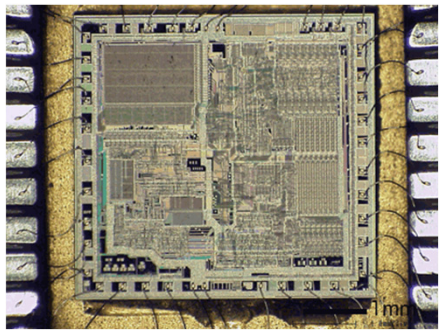

O. Paul, P. Ruther et al.
IMTEK, Univ. of Freiburg, Germany

# We Use Silicon as Texture Sensor Material

## Silicon as an Electron Device Material

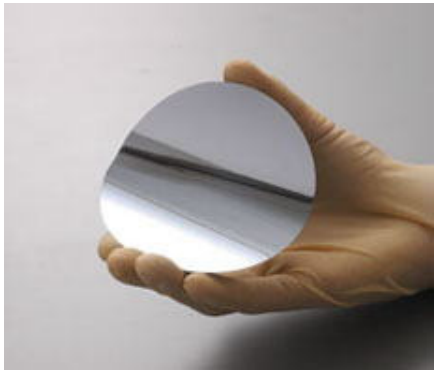
- Ideal for Integrated Circuits
- Suitable for Strain Sensor
- Multifunctional Integration

Intel 4004



## Silicon as a Mechanical Device Material

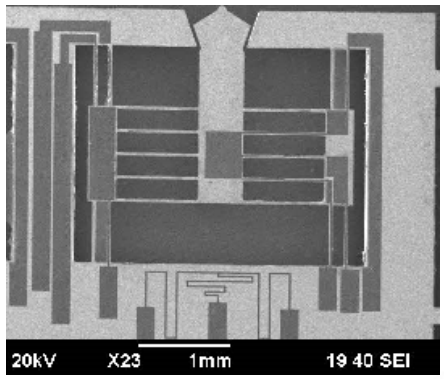
- Ideal Mechanical Deformation
- Supple Structure by Micromachining
- Faster Response and Motion



## Tactile Sensor Made of Silicon can Realize;

- High Spatial Resolution (~1μm or less)
- High Time Resolution (~2kHz or more)
- High Signal Resolution (~10μN or less)

# “Basic Nano-Tactile Sensor”




Surface Shape

Friction

Contactor tip

50μm

Reference plane

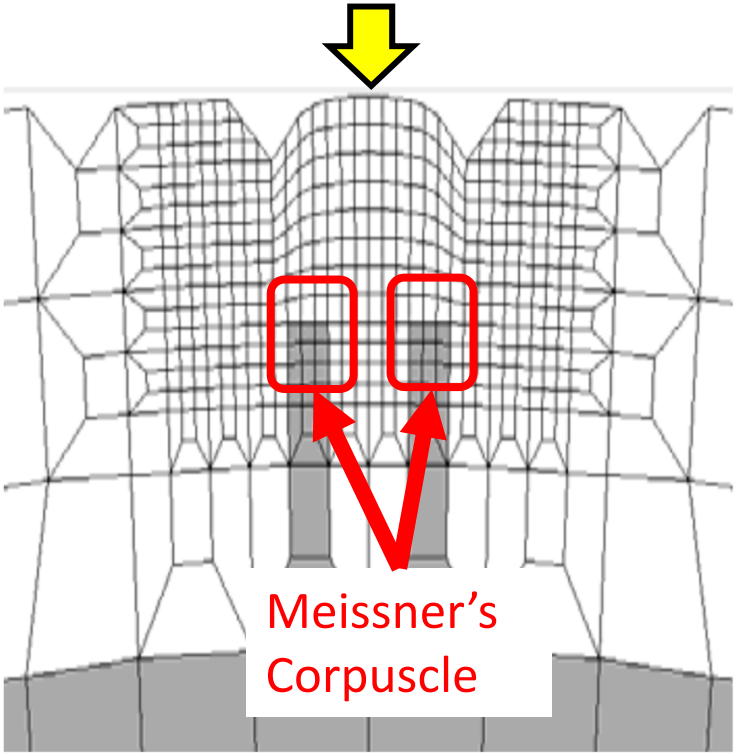
Contactor Sticking out from the Plane

Frictional Force Detectors

Surface Shape Detector

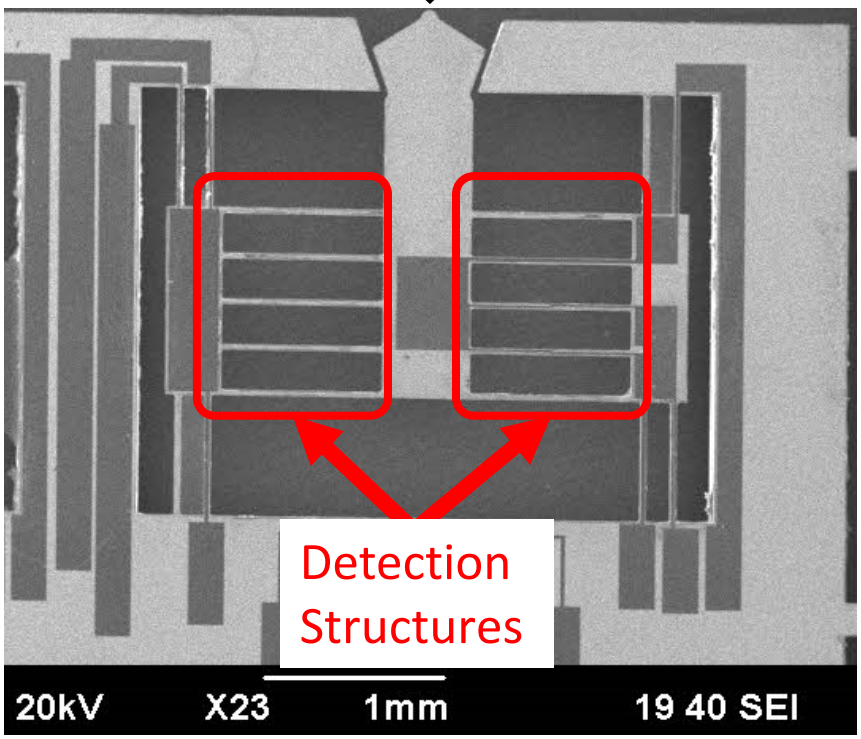
# Similarity: Single Fingerprint Sensor

Fingerprint




"Model of Fingerprint of Human"
T. Maeno et al. JSME C,
Vol. 71, No.701, pp. 245-250, 2005

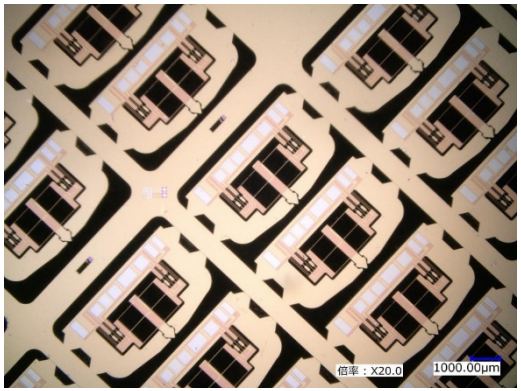
Contactor Tip

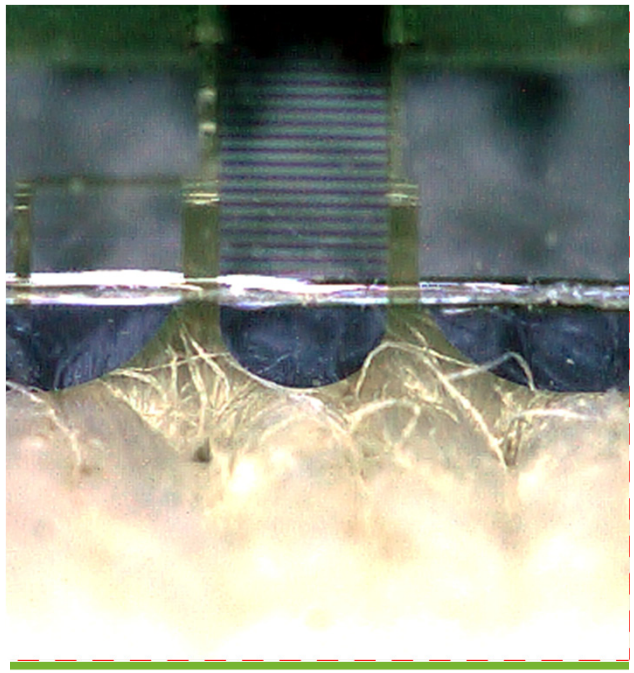


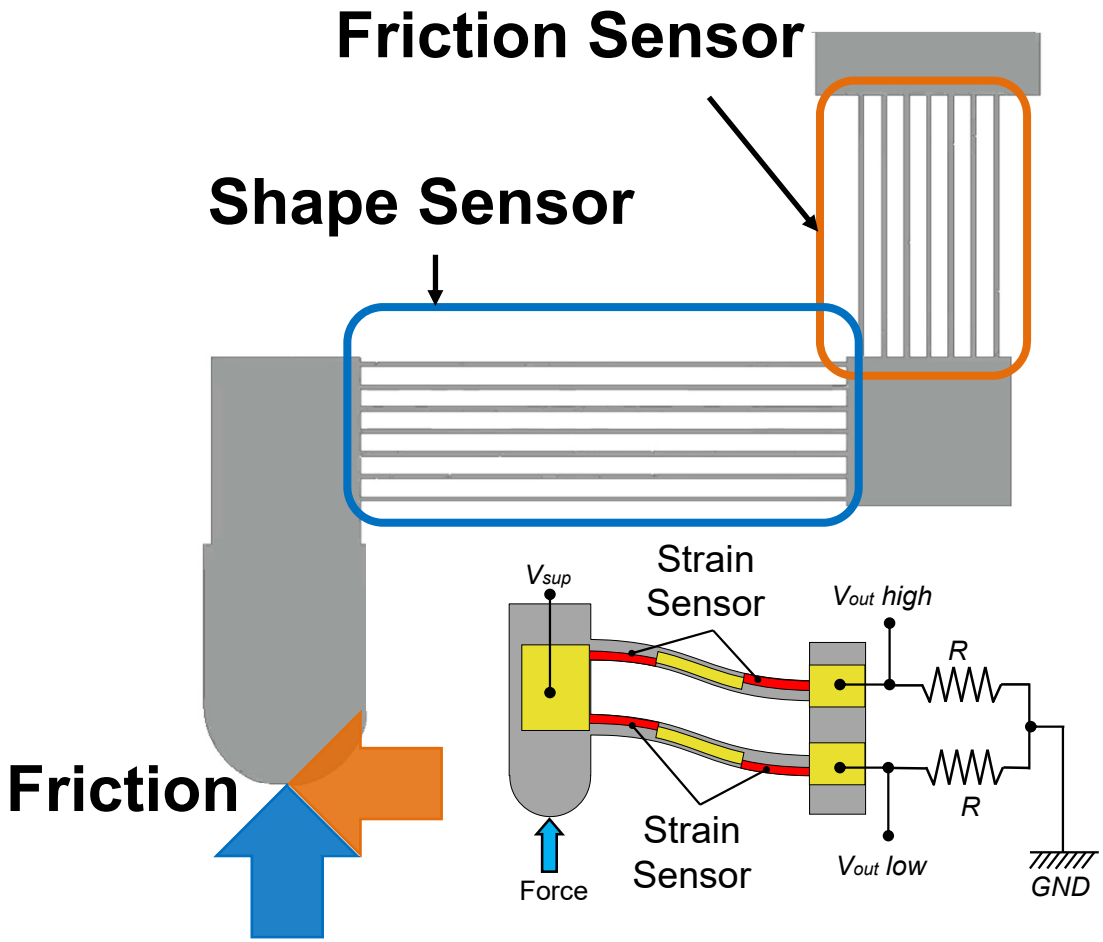

Nano-Tactile Sensor Device
Kagawa University CREST Project

# Similarity: Single Fingerprint Sensor

Nano Tactile Sensor Chips on Wafer



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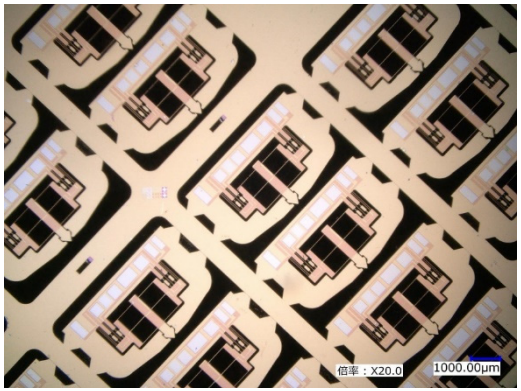
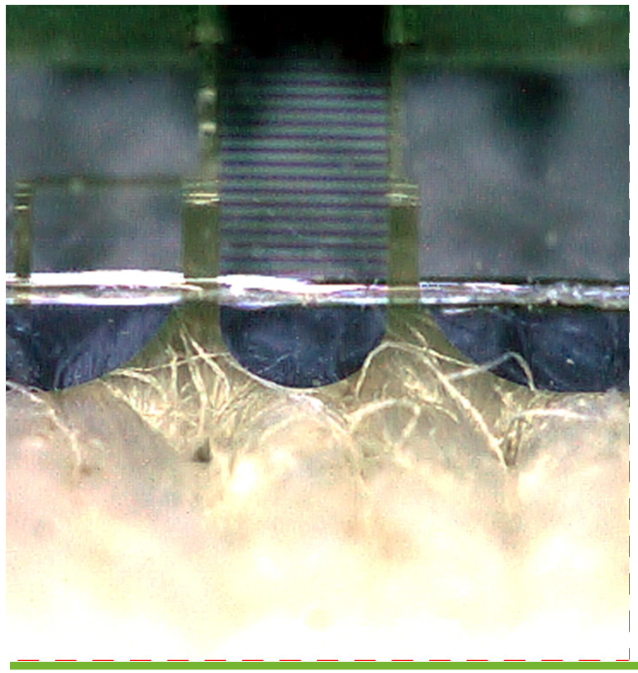
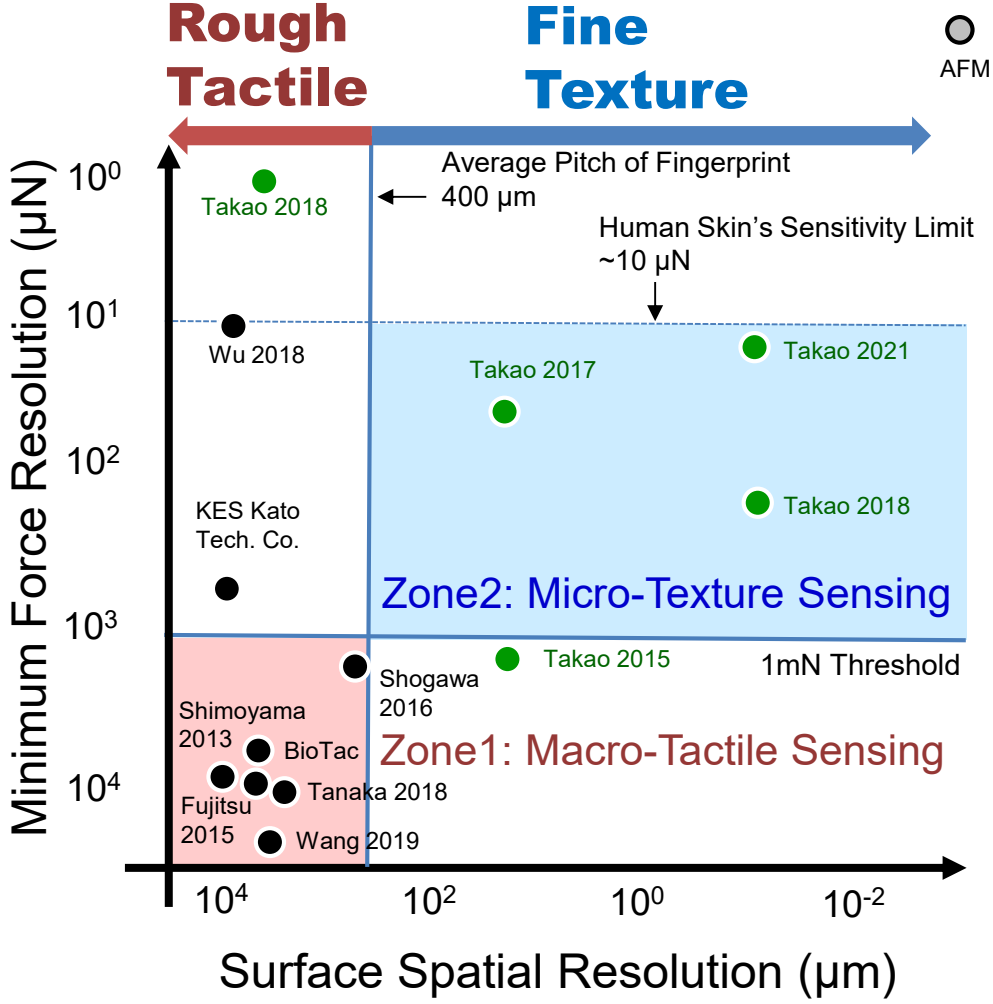
# Similarity: Single Fingerprint Sensor

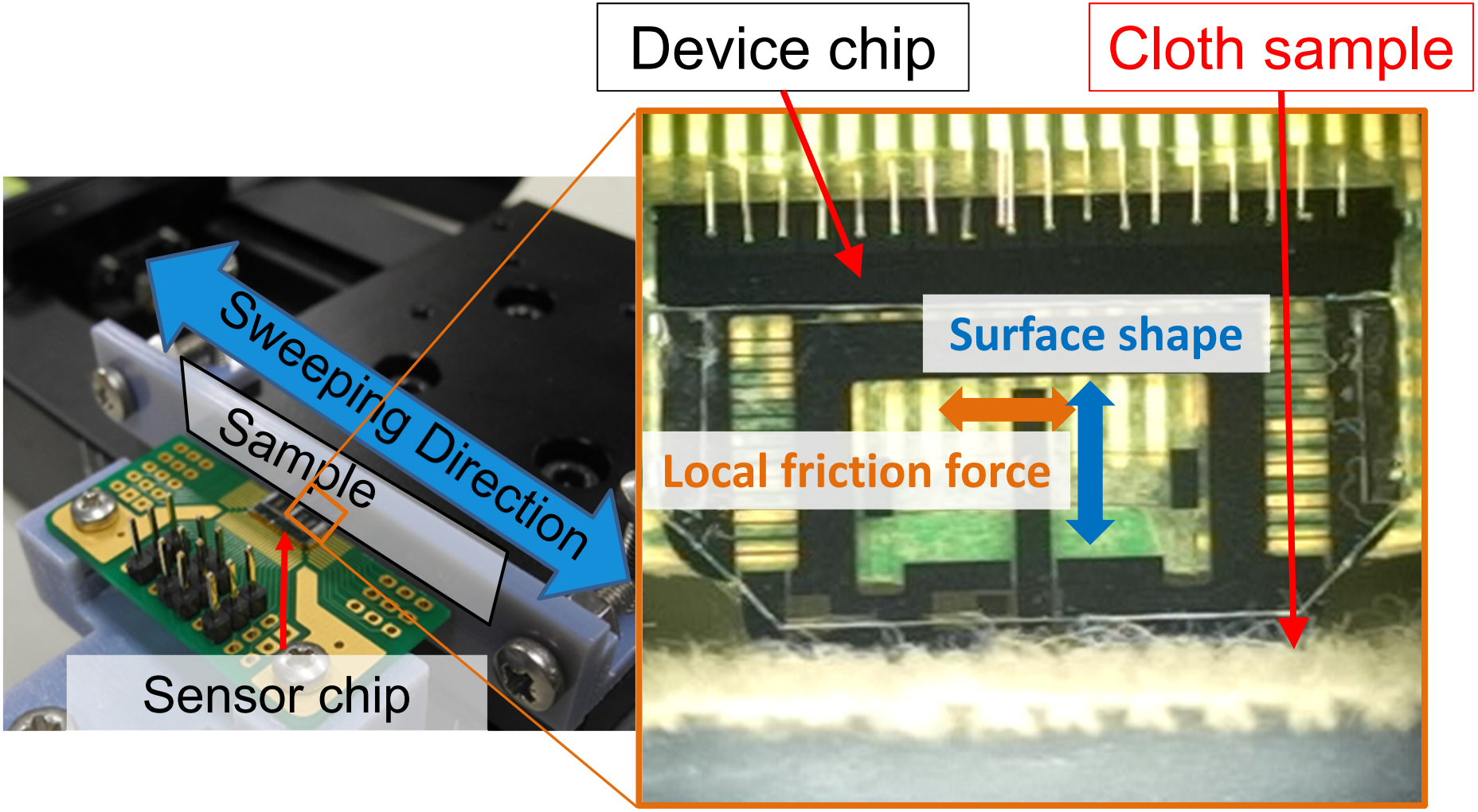
Nano Tactile Sensor Chips on Wafer



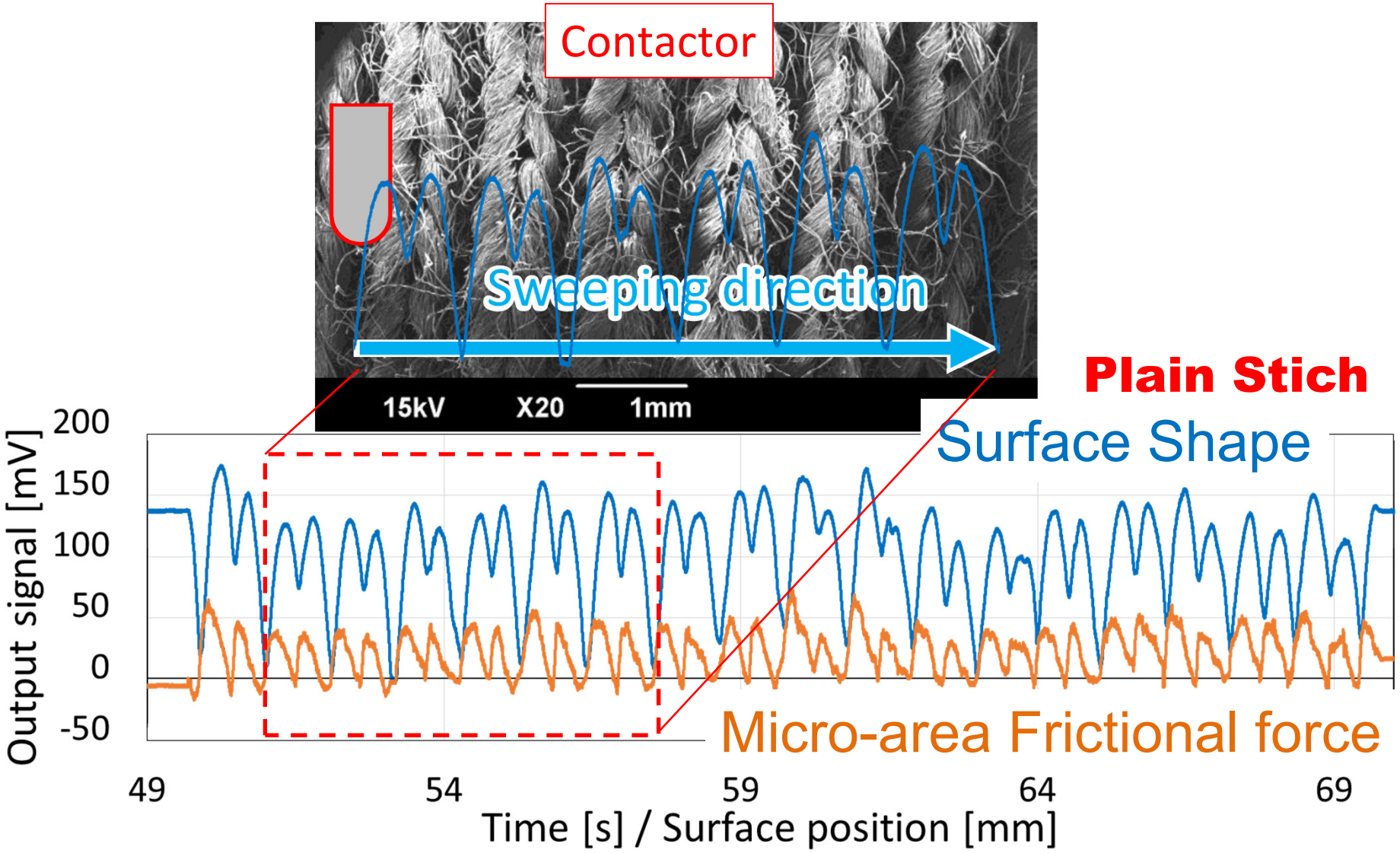


# “Soft Cloth” Measurement

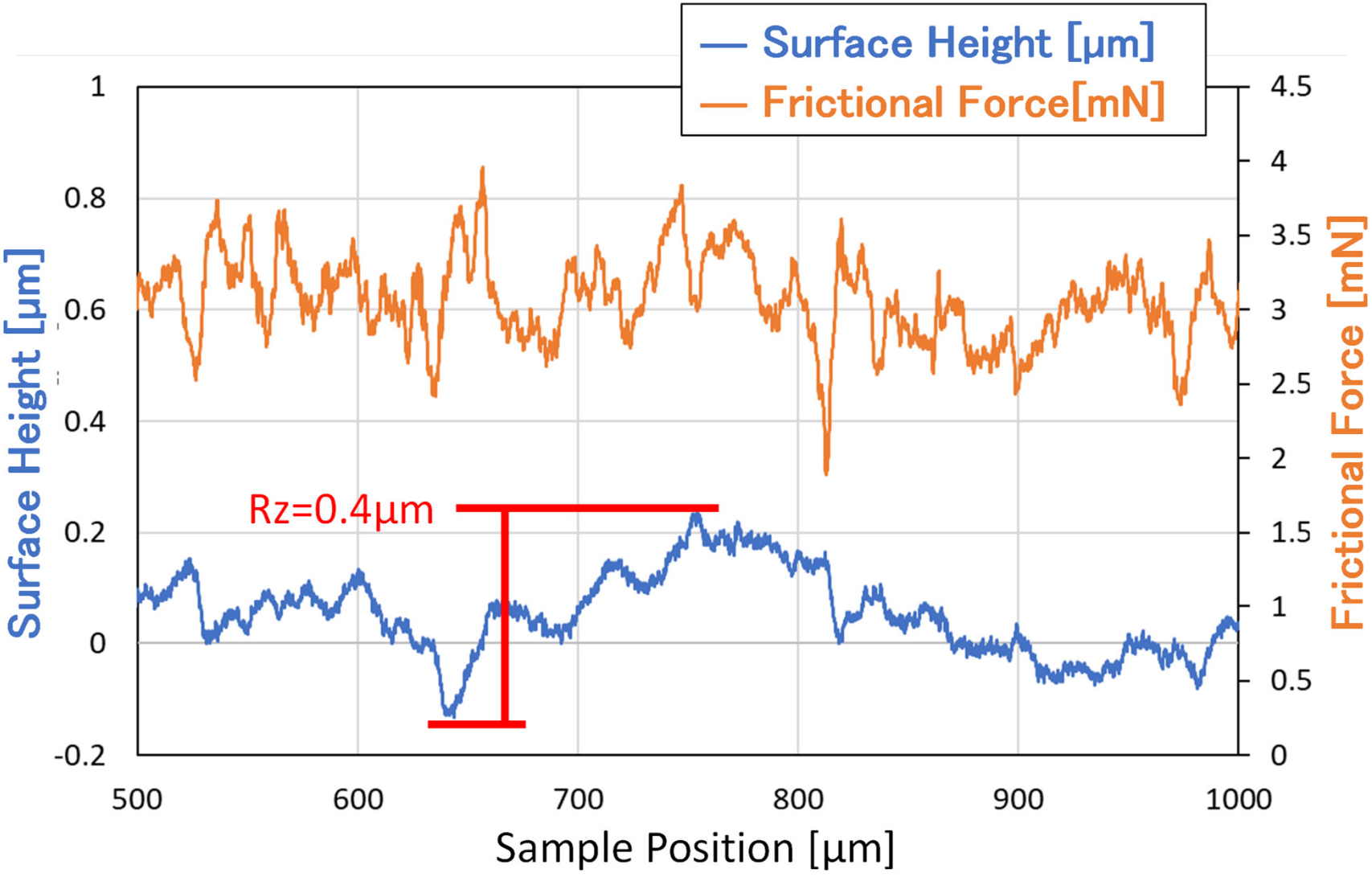



**Plain Stich Cloth**

# Tactile Waveforms on Plain Stich



# Tactile Sense Obtainable in Submicron!

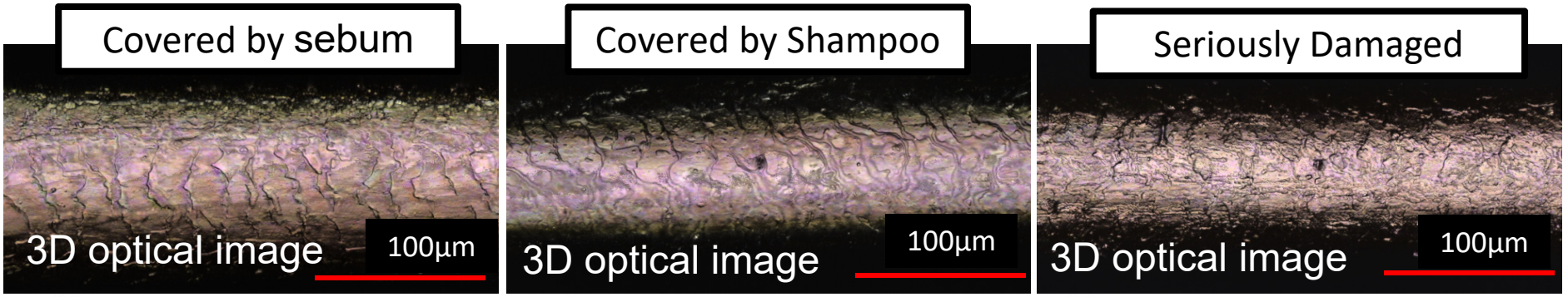


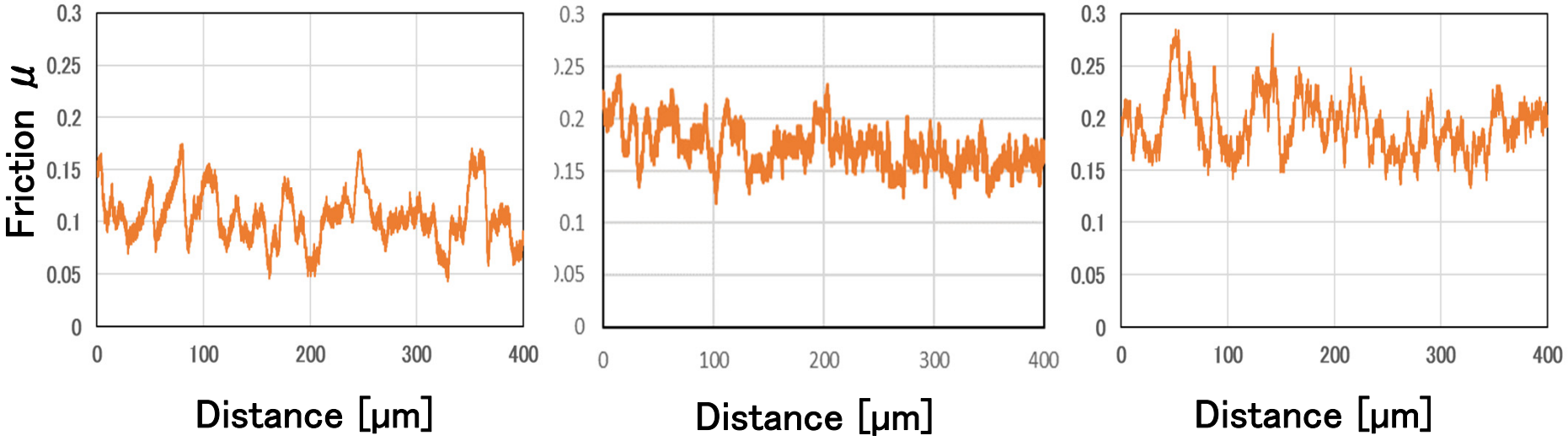
# Tactile Waveform on Human Hair

1. Before Shampoo

2. After Shampoo

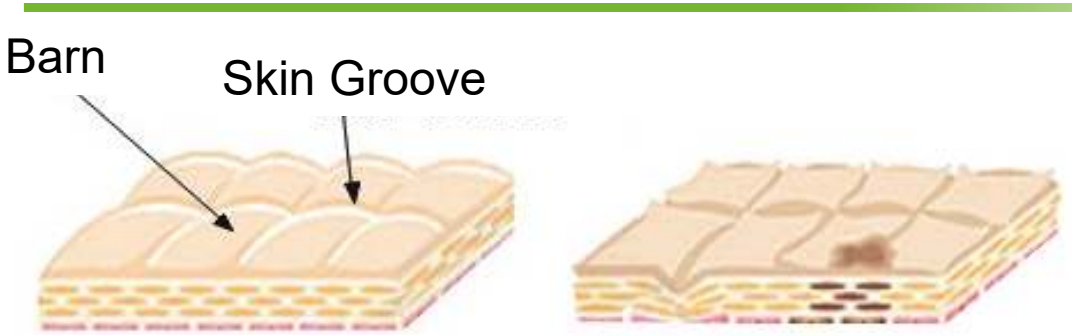
3. Wash by a Soap




The same hair sample is used

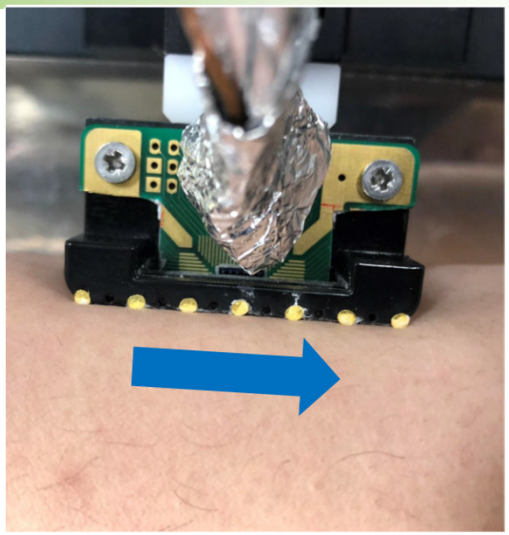
# Tactile Waveform on Human Skin

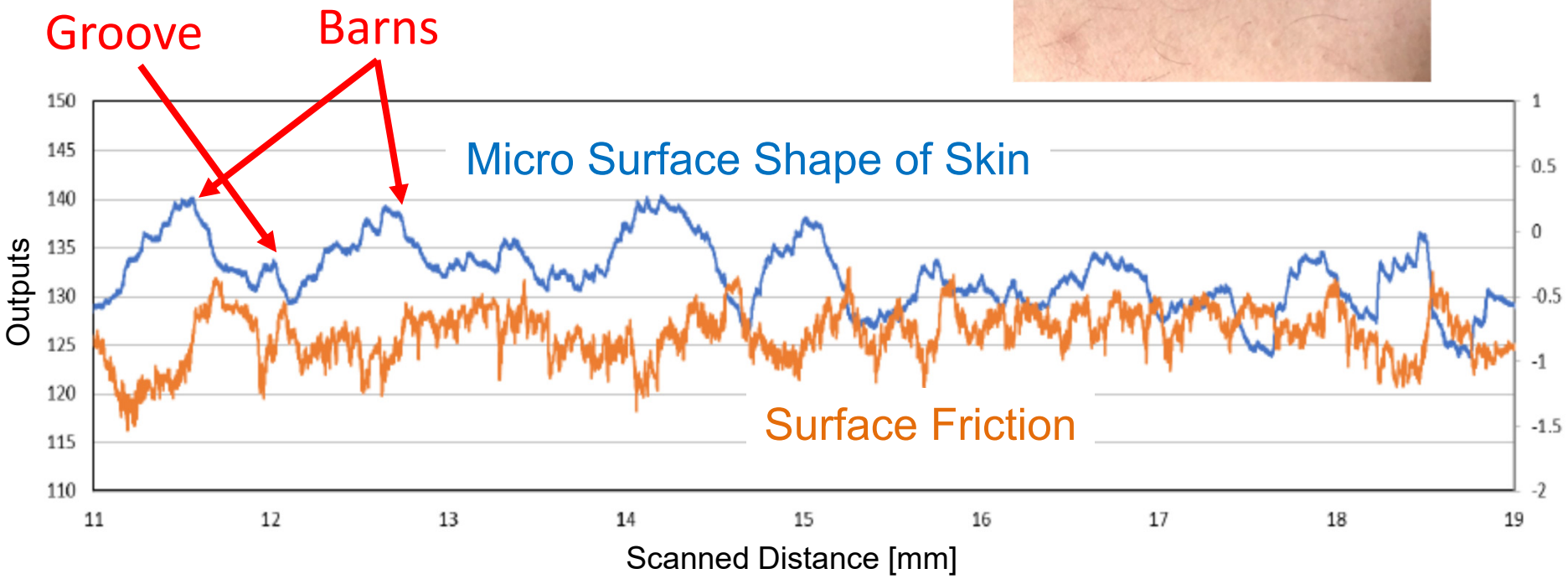



Younger Skin

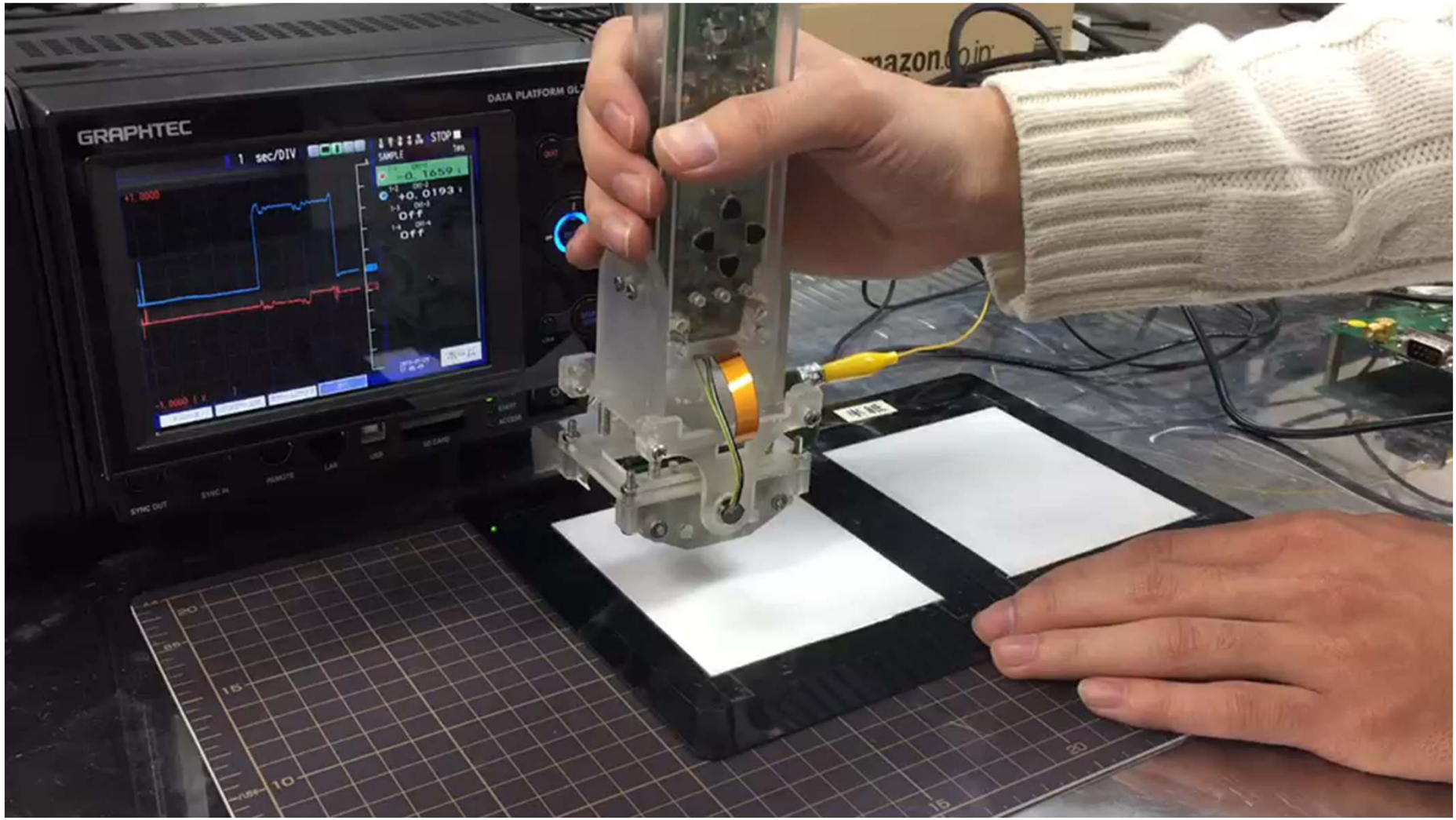


Aged Skin





# 1st-Gen.“Touch-Feeling Scanner”

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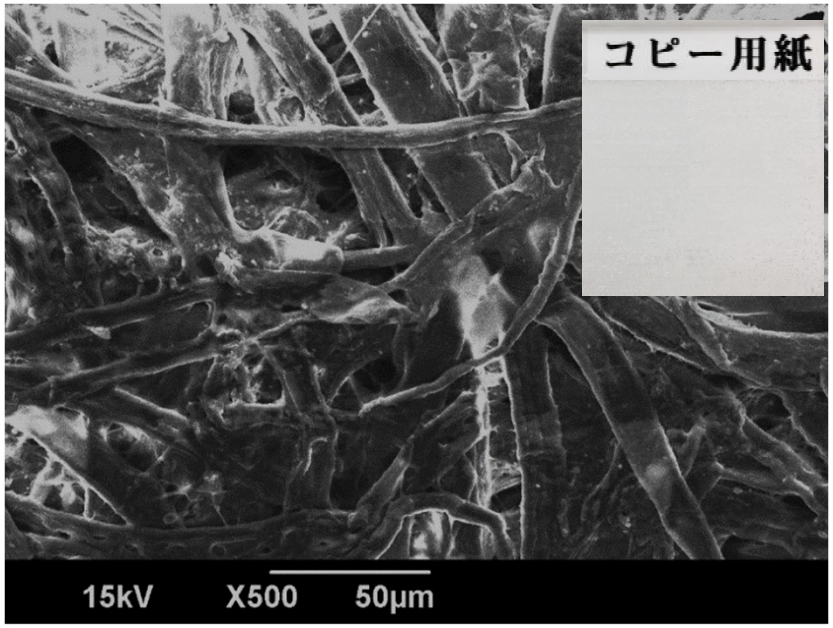
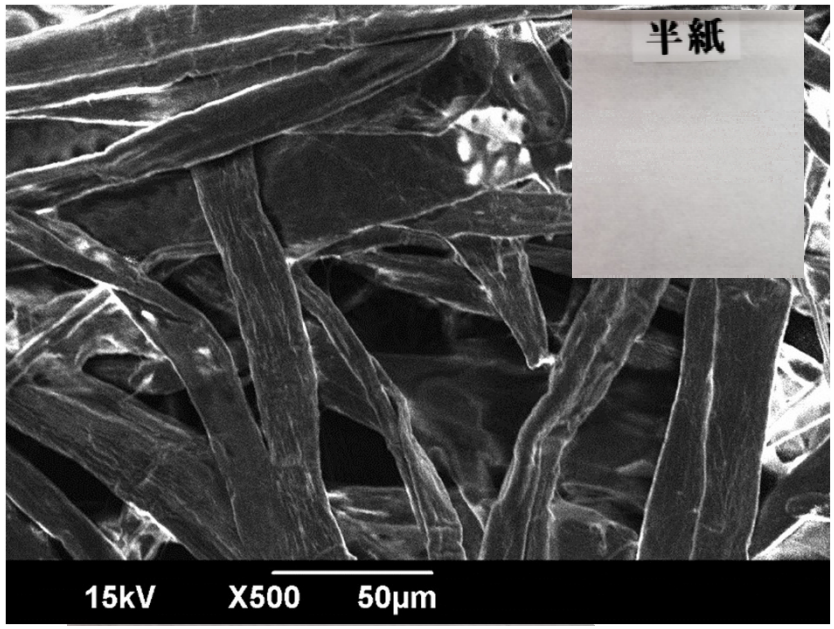
Core Research for Evolutionary Science and Technology

# Structures of Paper Surface




High Quality Paper
(Smooth and Low Friction)

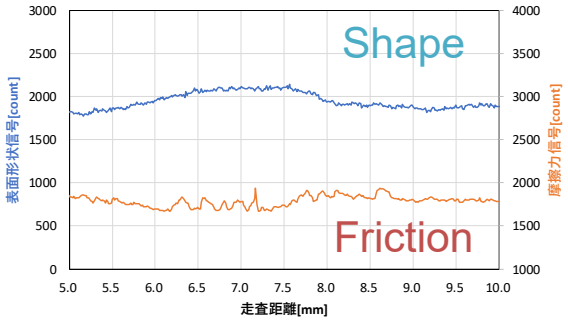



Low Quality Paper
(Rough and Connective)

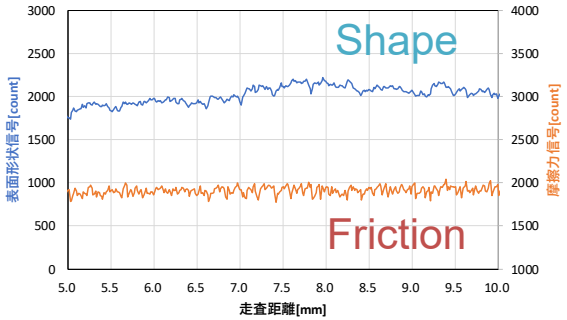
- Difference of surface appearance is unexpectedly small.
- Nano-Tactile Sensor can distinguish the small difference.

# Touch Feeling Data of PAPERs

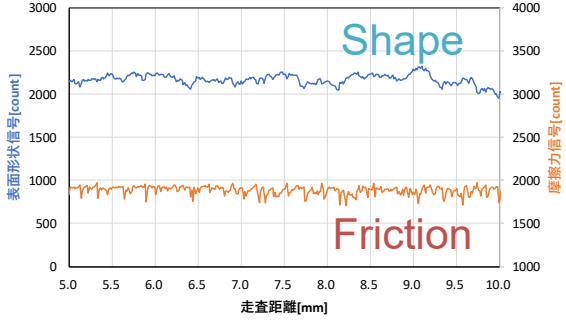
## Glossy Photo Paper



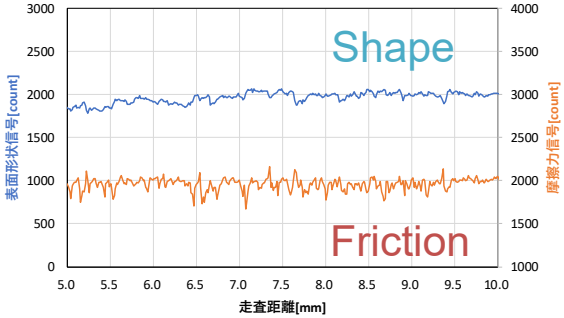

## Matte Photo Paper



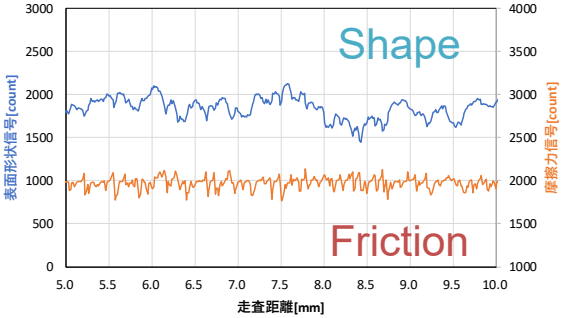

## Kent Paper



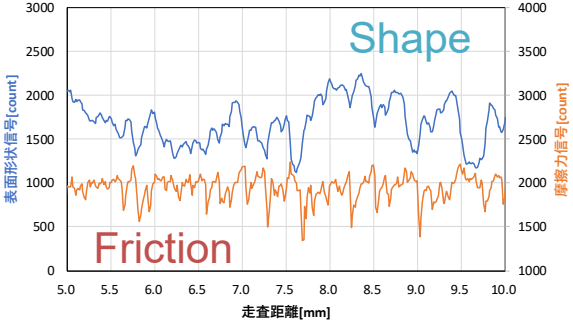

## High Grade Paper



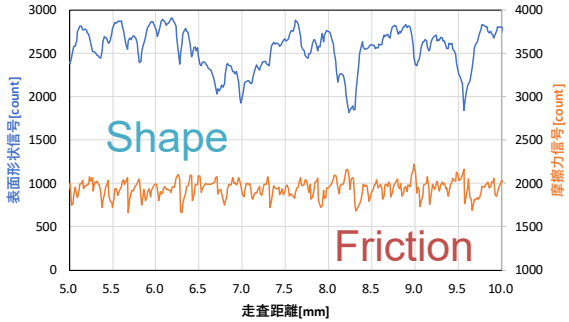

## Middle Grade Paper



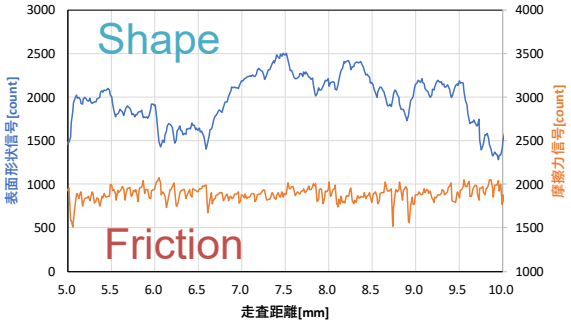

## Low Grade Paper



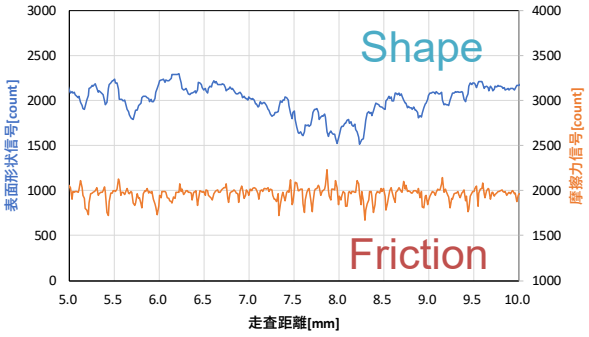

## Japanese Traditional Paper



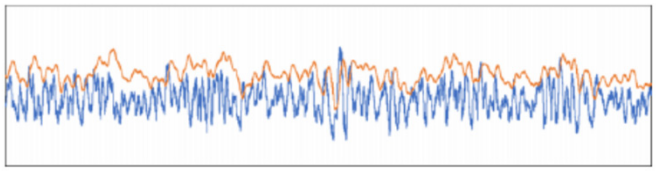

## Painting Paper



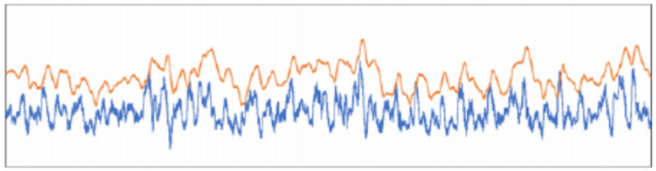

## Kraft Paper



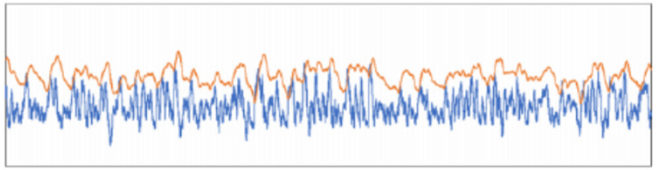
# Very Small Difference (Tissue Papers)



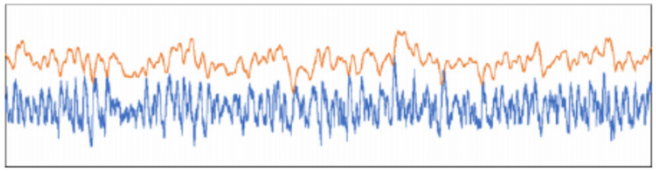
A. Nepia's Nepi-Nepi (0.2JPY/Sheet)



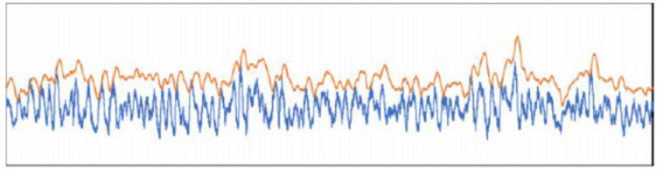
B. Nepia's Premium Soft (0.3JPY/Sheet)



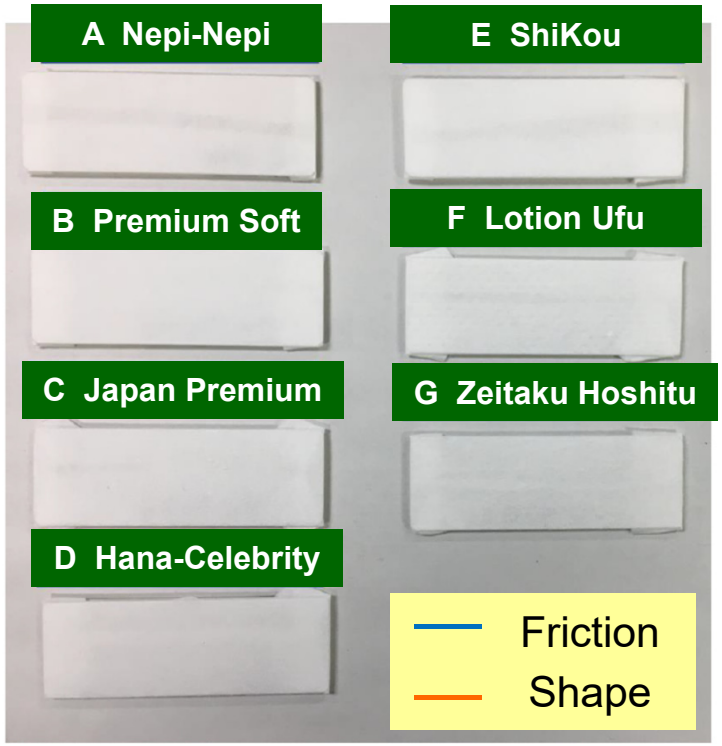
C. Nepia's Japan Premium (1.0JPY/Sheet)

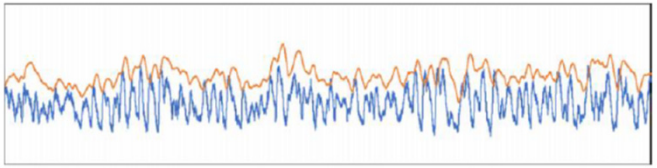


D. Nepia's Hana-Celebrity (2.0JPY/Sheet)

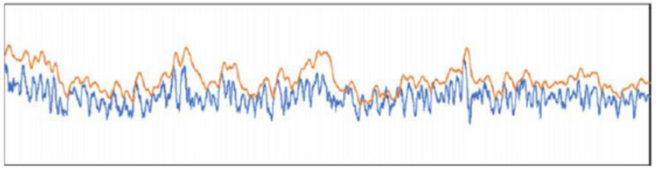


E. Kleenex's Shikou (5.0JPY/Sheet)



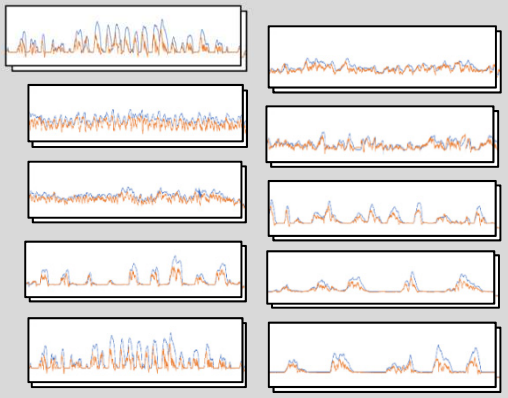
F. Elleair's Lotion Ufu (2.0JPY/Sheet)



G. Elleair's Zeitaku-Hoshitsu (1.5JPY/Sheet)

# Neural Network for Tactile Discrimination

Training Data



7Class Tissue Papers


Labels

Input Layer

Convolution 1

Pooling 1

Convolution 2

Pooling 2

Convolution 3

Pooling 3

Convolution 4

Pooling 4

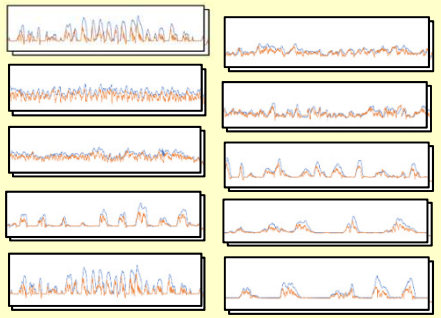
Fully Connected

Output

Activation Functions
Intermediate: ReLu Function
Output: Softmax Function
Loss: Cross Entropy Function
Optimization: Adam Optimizer

Trained Machine

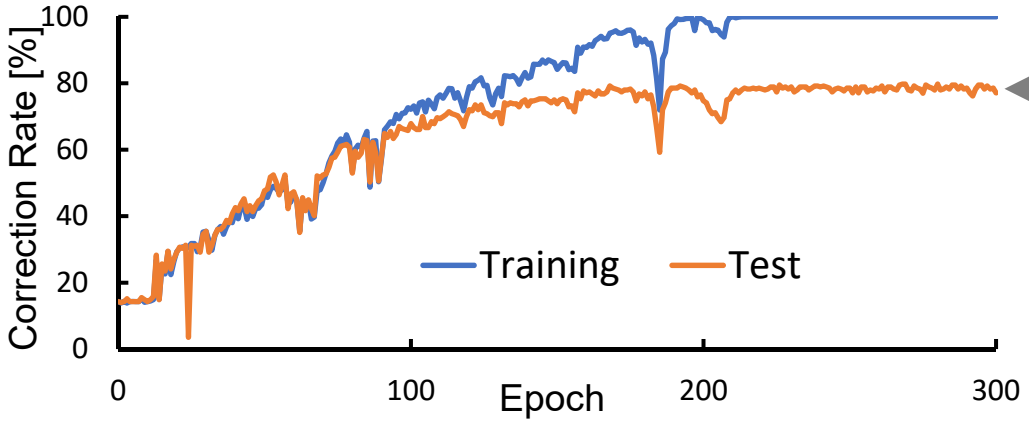
Evaluation



Test Data (Untrained)

Confusion Matrix

# Confusion Matrix (Deep Learning)




Correct Answer

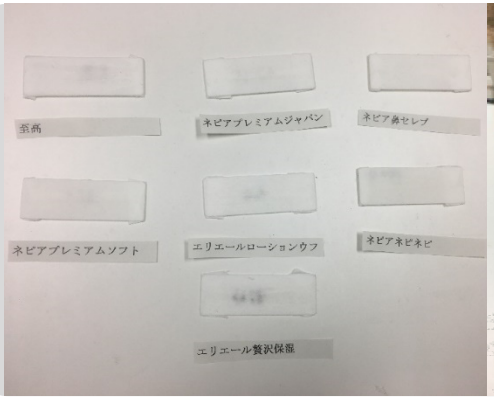
**80.4%**

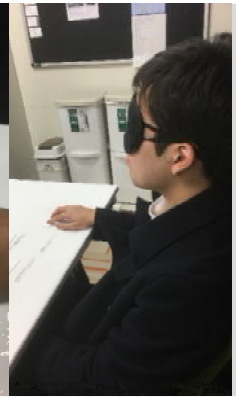
| Evaluation Input \ Output Probability | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|
| A. Nepia's Nepi-Nepi | 0.73 | 0.15 | 0.01 | 0.04 | 0.08 | 0.00 | 0.00 |
| B. Nepia's Premium Soft | 0.23 | 0.76 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 |
| C. Nepia's Japan Premium | 0.01 | 0.01 | 0.86 | 0.03 | 0.08 | 0.00 | 0.00 |
| D. Nepia's Hana-Celebrity | 0.01 | 0.01 | 0.01 | 0.84 | 0.08 | 0.04 | 0.02 |
| E. Kleenex's Shikou | 0.03 | 0.03 | 0.16 | 0.07 | 0.59 | 0.14 | 0.01 |
| F. Elleair's lotion Ufu | 0.00 | 0.00 | 0.01 | 0.12 | 0.09 | 0.74 | 0.04 |
| G. Elleair's Zeitaku-Hoshitsu | 0.00 | 0.00 | 0.00 | 0.07 | 0.00 | 0.00 | 0.93 |

Ave. Compliance

**78.0%**

# Confused Matrix (Human's Finger)



1. Learning and Training for 20min.
2. "Vision Removal" with Eye Mask
3. Discrimination Test with Samples

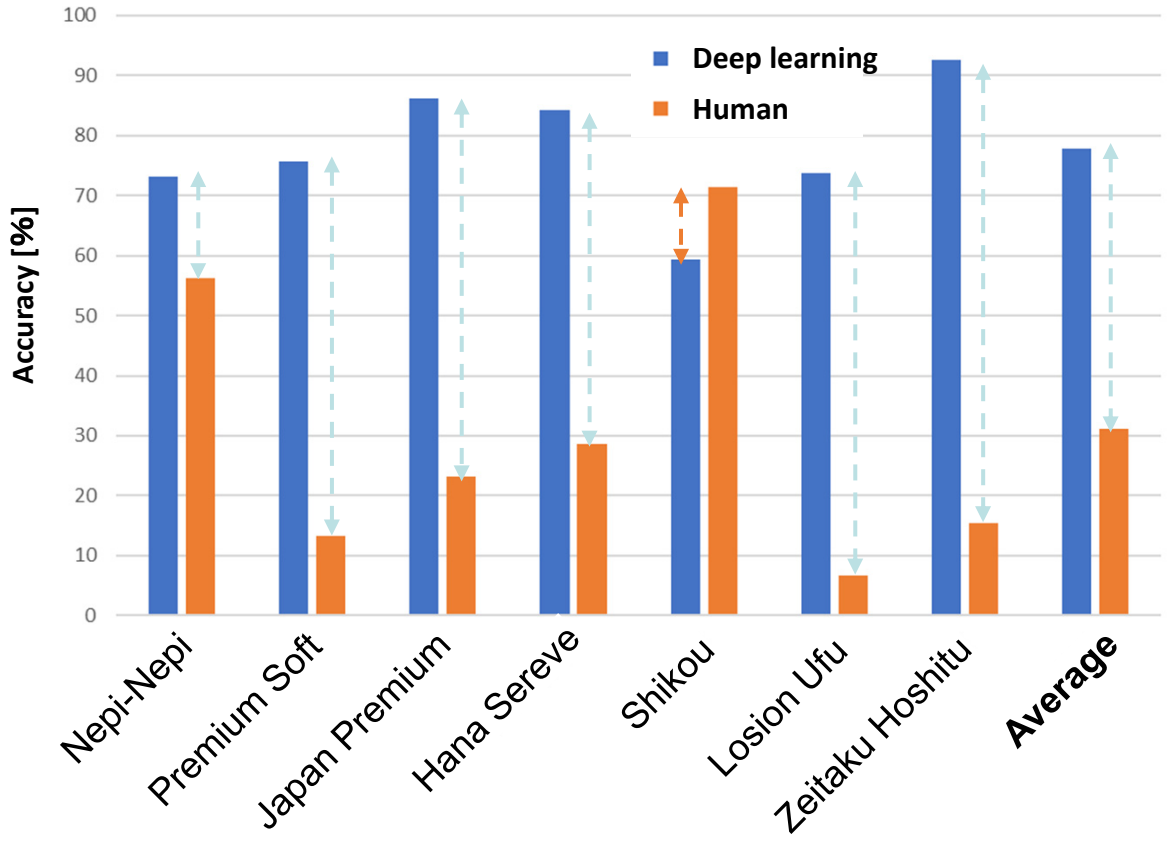
Average Age: 22

| Evaluation Input | Output Probability A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|
| A. Nepia's Nepi-Nepi | 0.56 | 0.25 | 0.00 | 0.13 | 0.00 | 0.06 | 0.00 |
| B. Nepia's Premium Soft | 0.67 | 0.13 | 0.00 | 0.13 | 0.00 | 0.07 | 0.00 |
| C. Nepia's Japan Premium | 0.00 | 0.23 | 0.23 | 0.08 | 0.08 | 0.23 | 0.15 |
| D. Nepia's Hana-Celebrity | 0.07 | 0.07 | 0.21 | 0.29 | 0.00 | 0.07 | 0.29 |
| E. Kleenex's Shikou | 0.00 | 0.00 | 0.07 | 0.07 | 0.71 | 0.00 | 0.14 |
| F. Elleair's lotion Ufu | 0.00 | 0.20 | 0.20 | 0.20 | 0.07 | 0.07 | 0.27 |
| G. Elleair's Zeitaku-Hoshitsu | 0.00 | 0.39 | 0.00 | 0.08 | 0.15 | 0.23 | 0.15 |

Correct Answer

**31%**

# Trained Sensor vs. Human



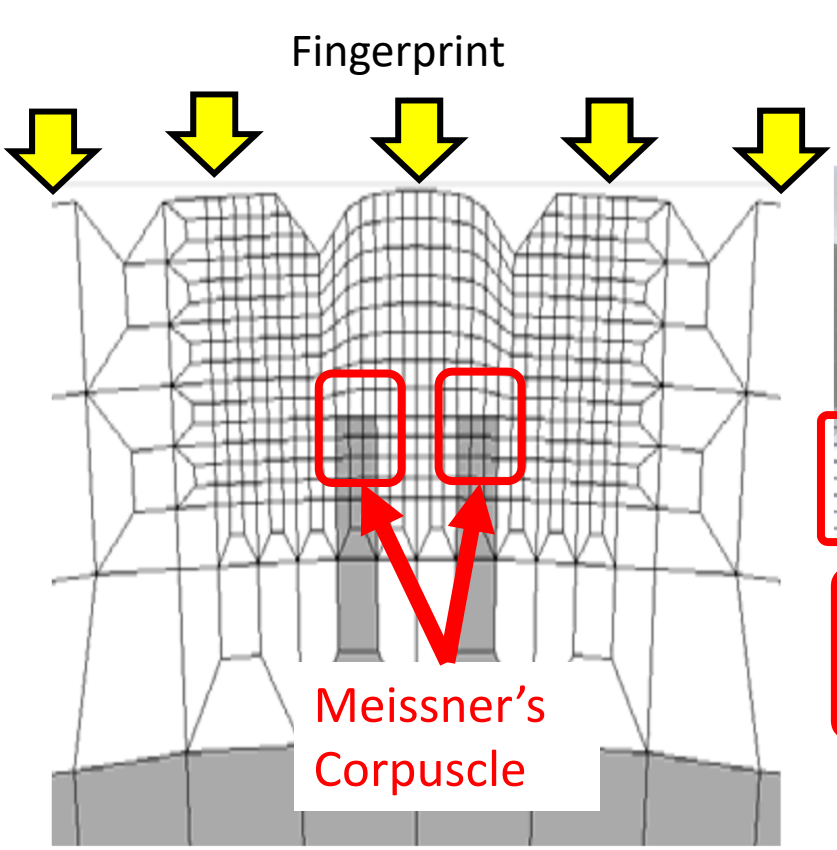

Deep Learning

80%

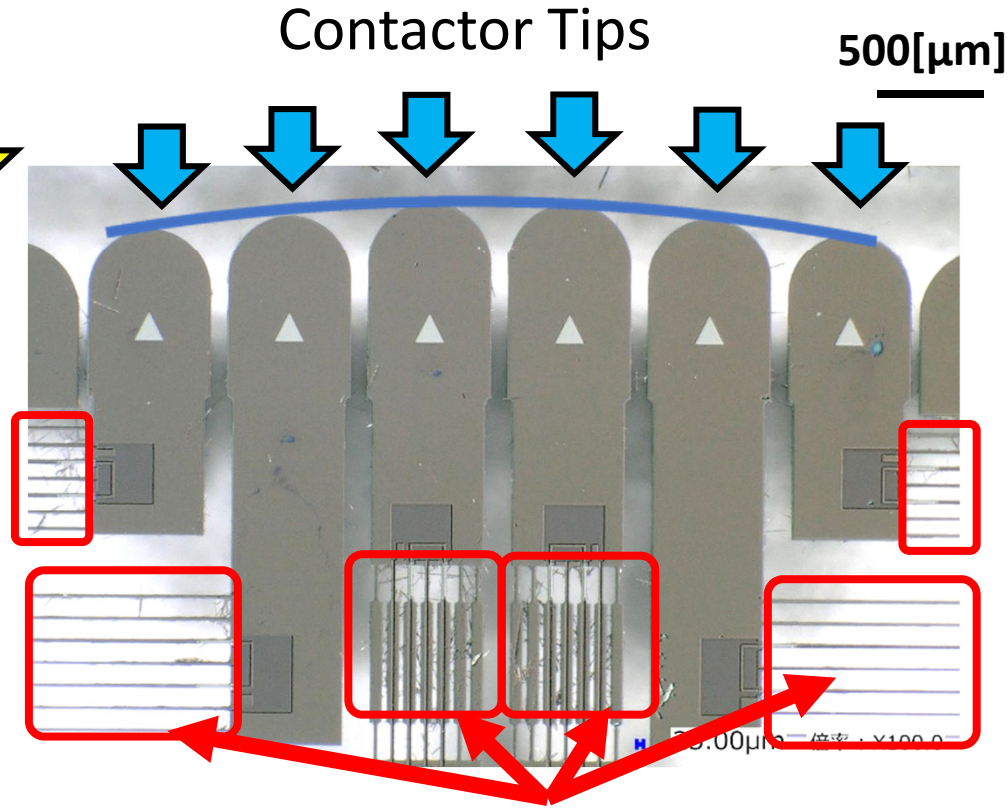
Human

31%

# Similarity: Multiple Fingerprint Sensor

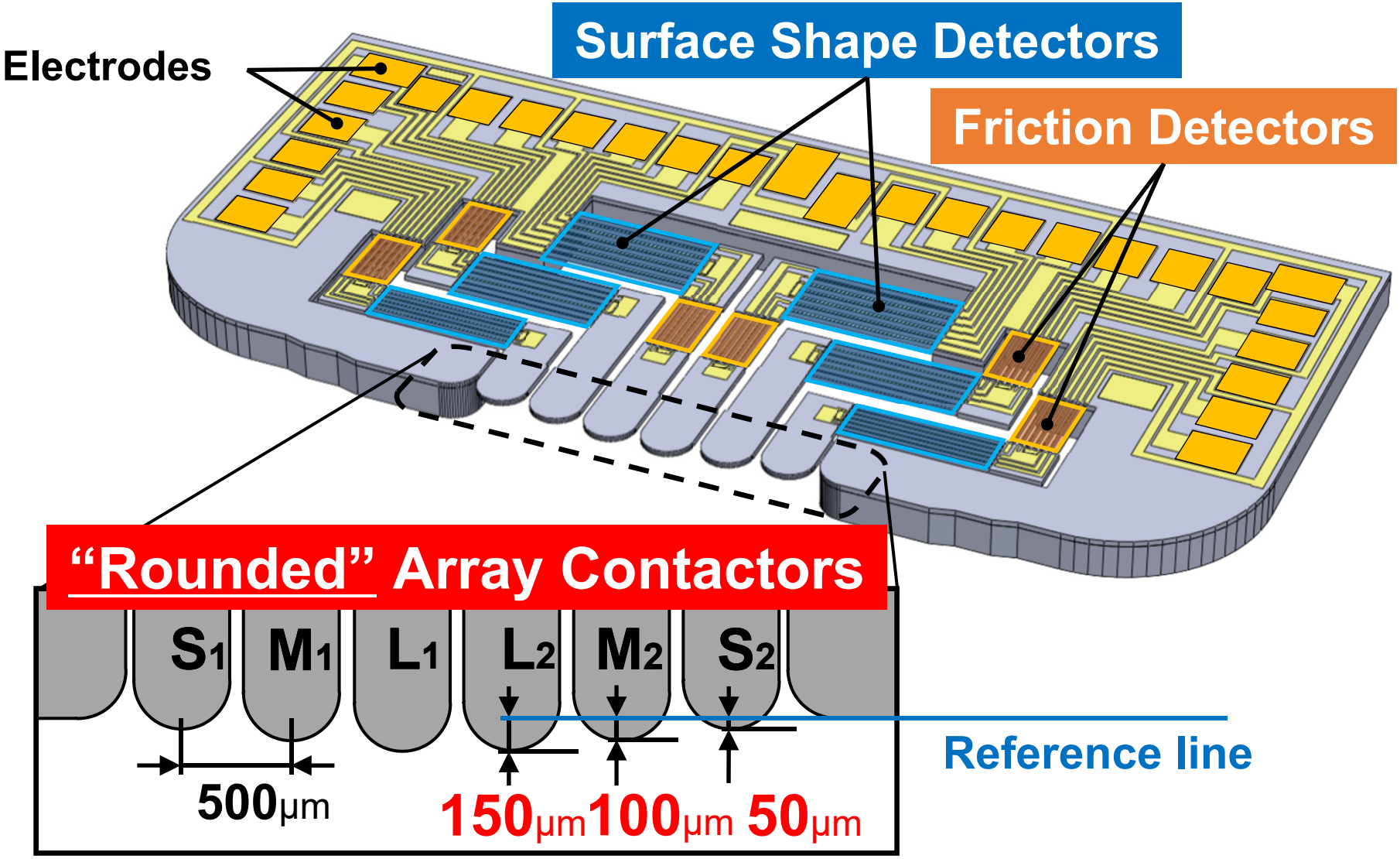



"Model of Fingerprint of Human"
T. Maeno et al. JSME C,
Vol. 71, No.701, pp. 245-250, 2005

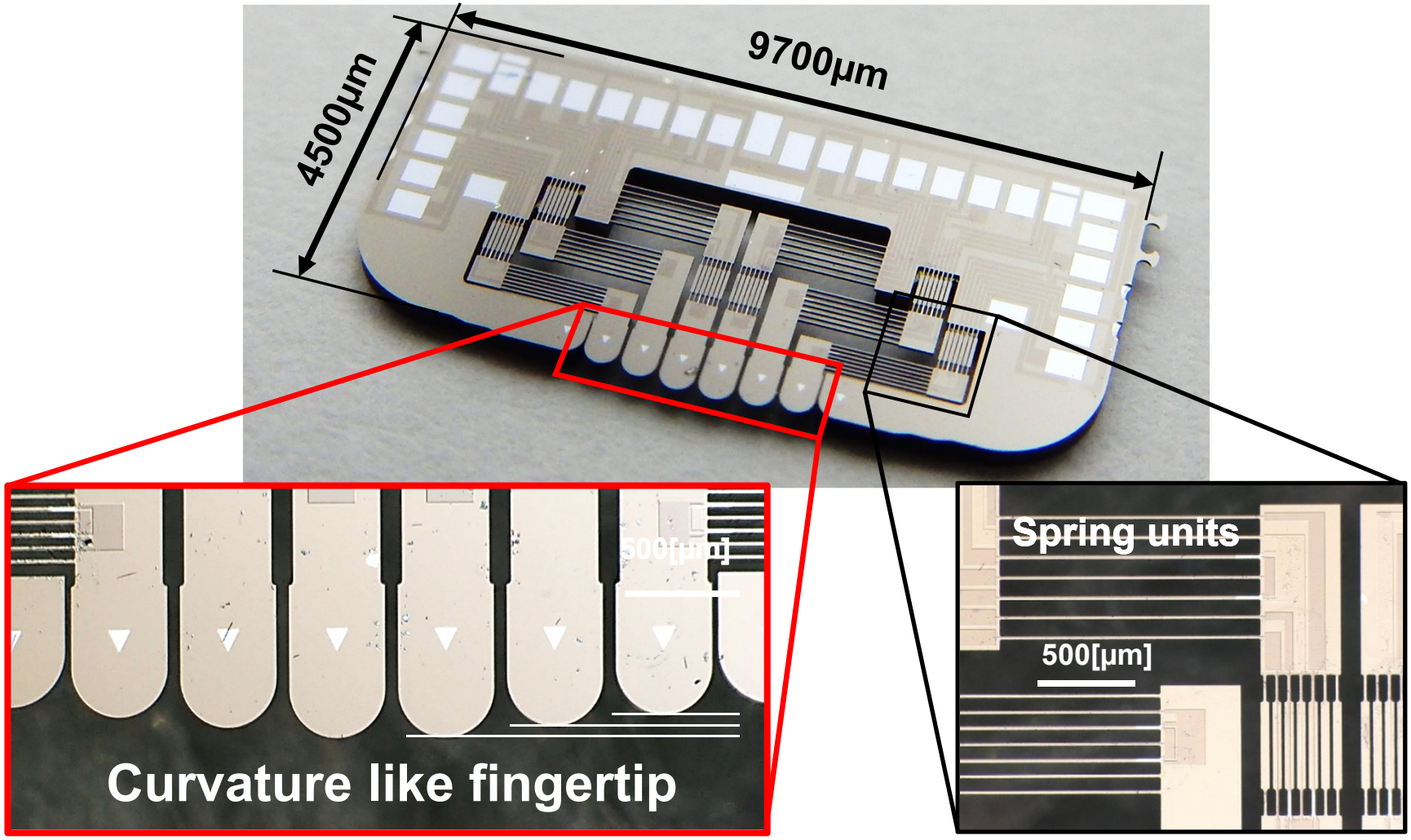



Nano-Tactile Sensor Array
The Latest Device realized in 2018
H. Takao et al., IEEE MEMS2019

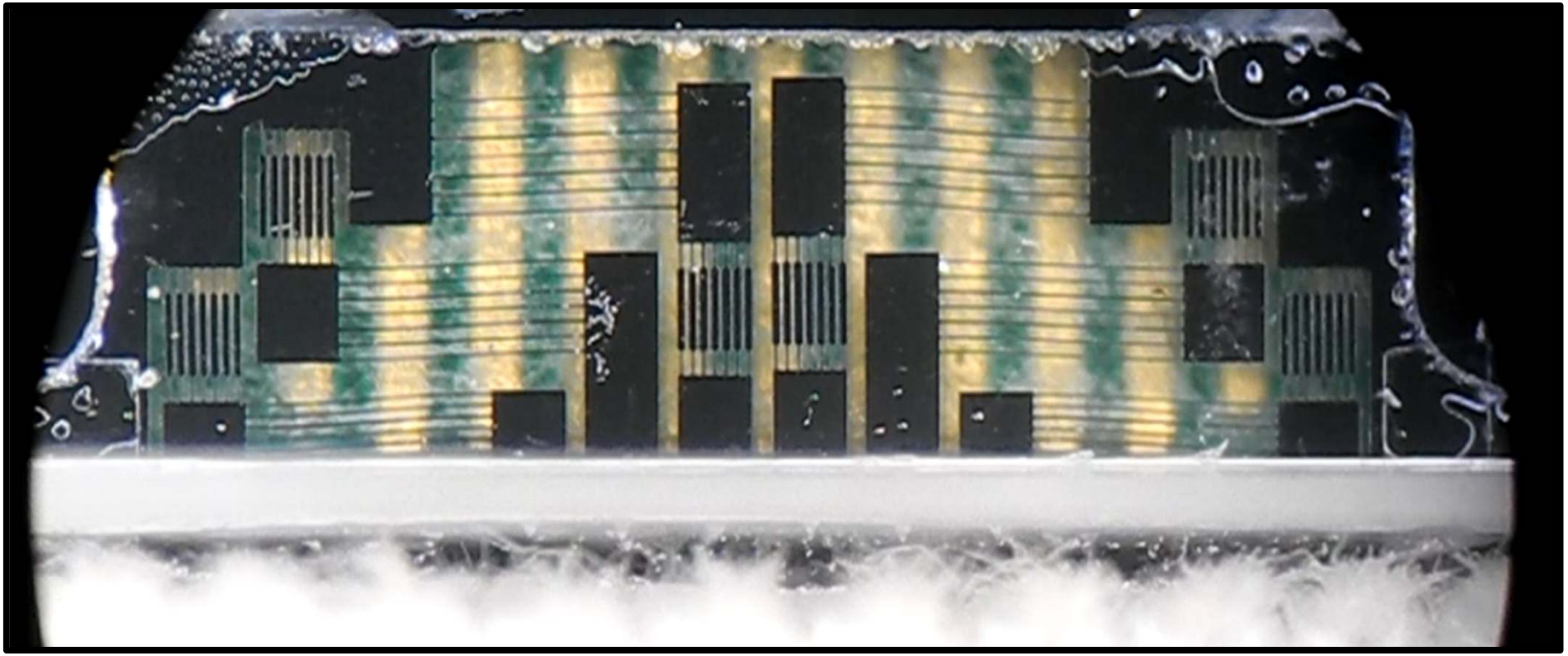
# 2nd Generation Sensor Chip (6 Array)



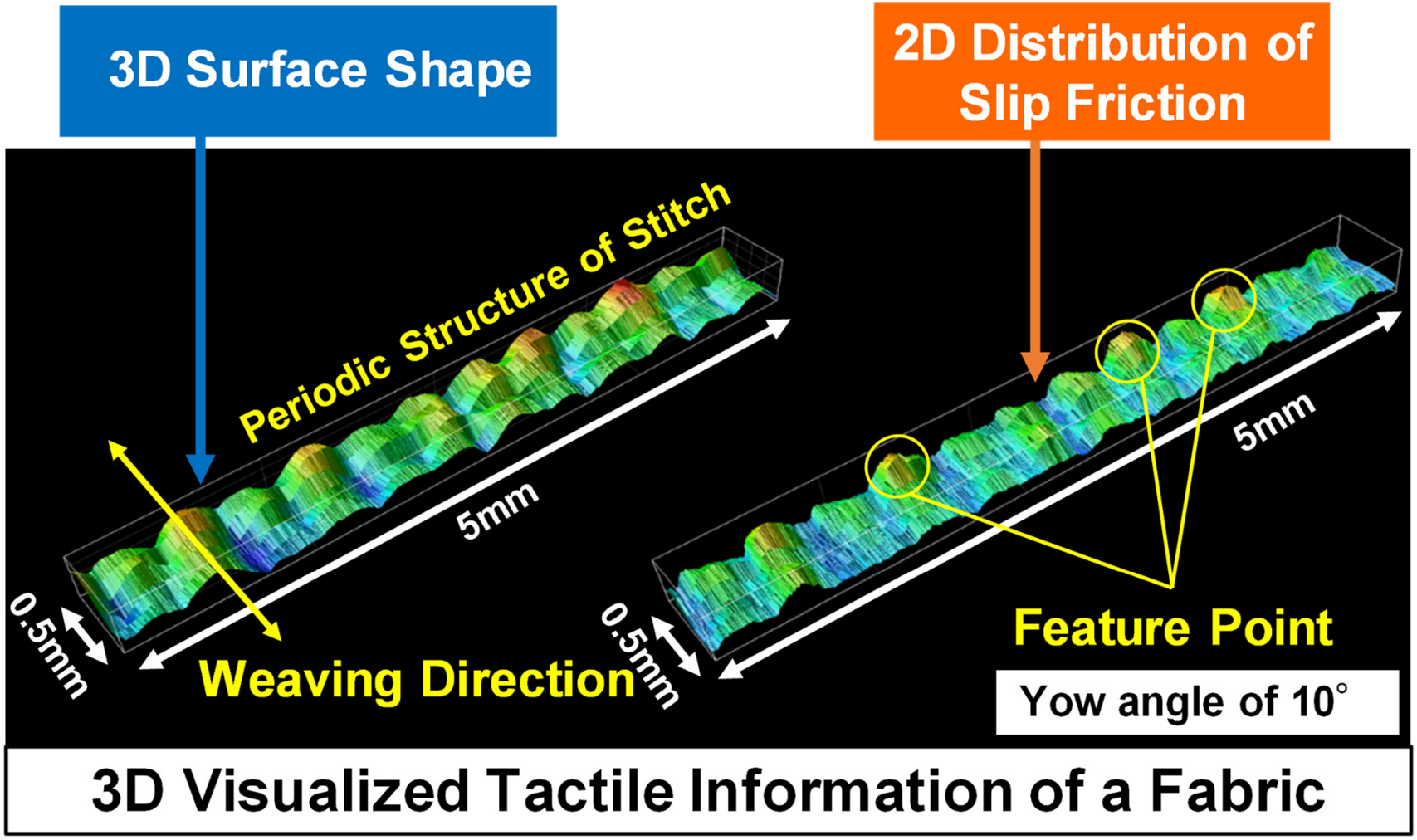
# 2nd Generation Sensor Chip (6 Array)



# Distributions of Tactile Information

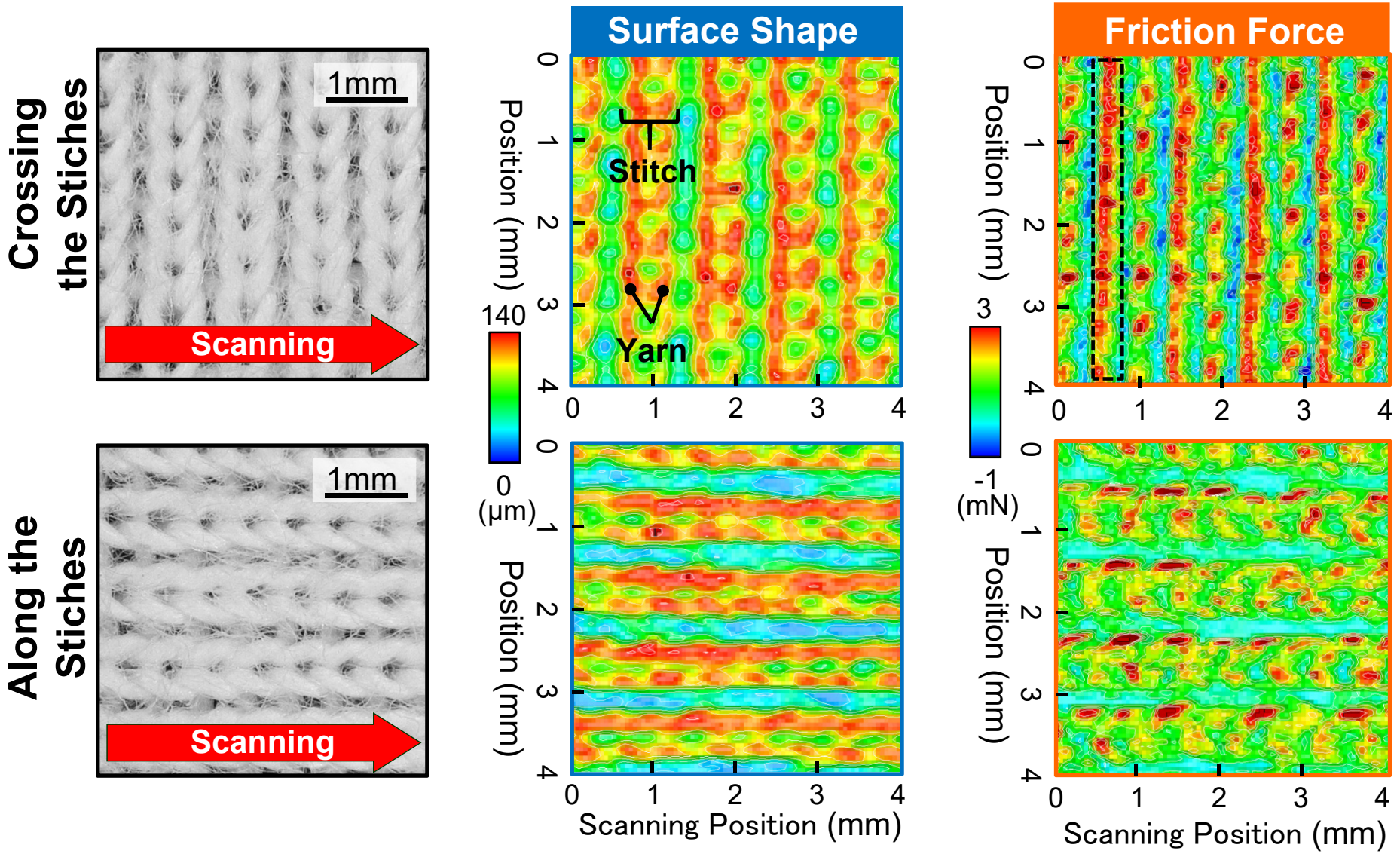


# Distributions of Tactile Information




3D Visualized Tactile Information of a Fabric

# Directional Touch Feeling Discrimination



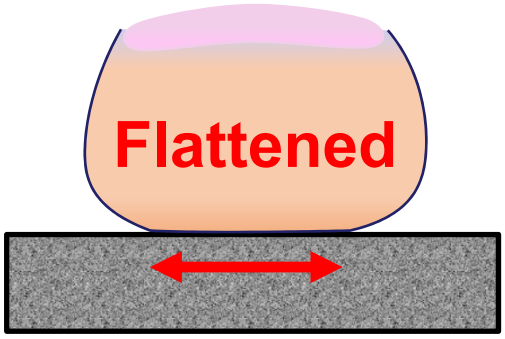

KAGAWA UNIVERSITY

**Feature in Friction is Detected**

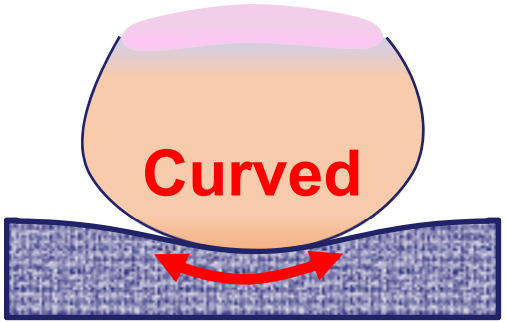
TAKAO LABOLATORY

# “Elasticity” and Its Distribution

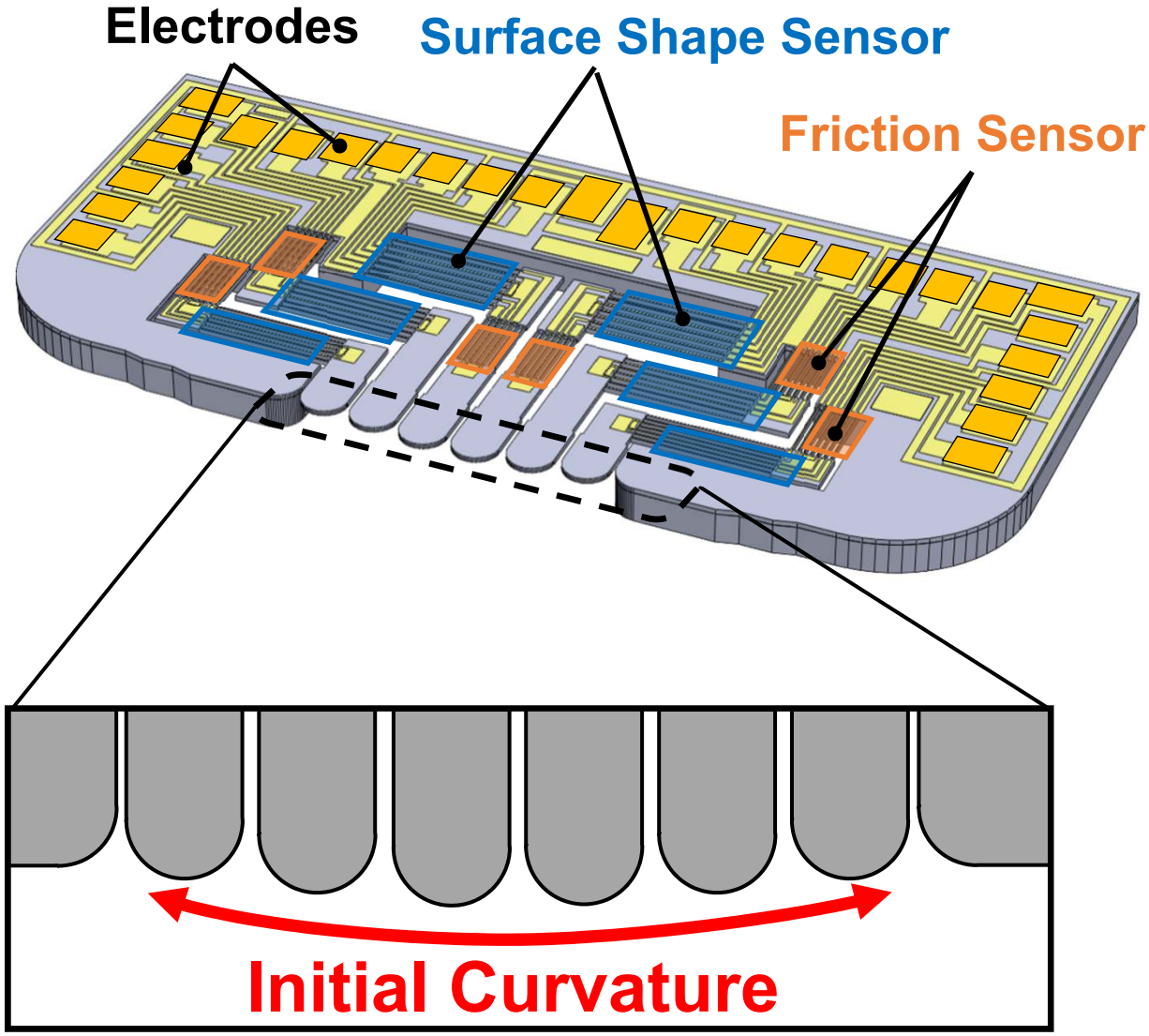
## Hardness Recognition



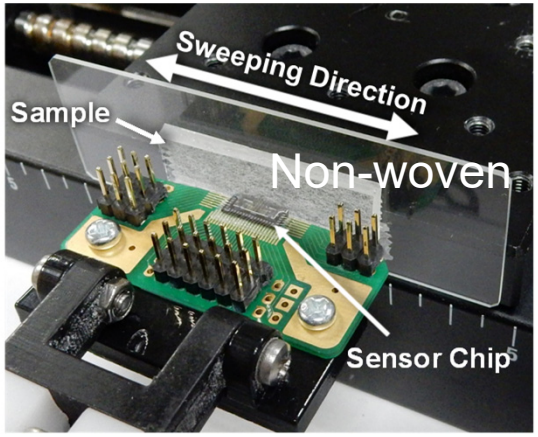

Harder Material

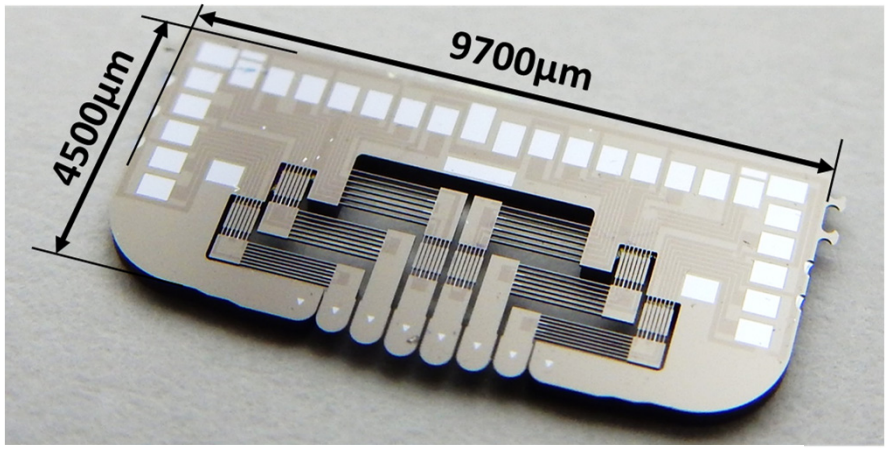


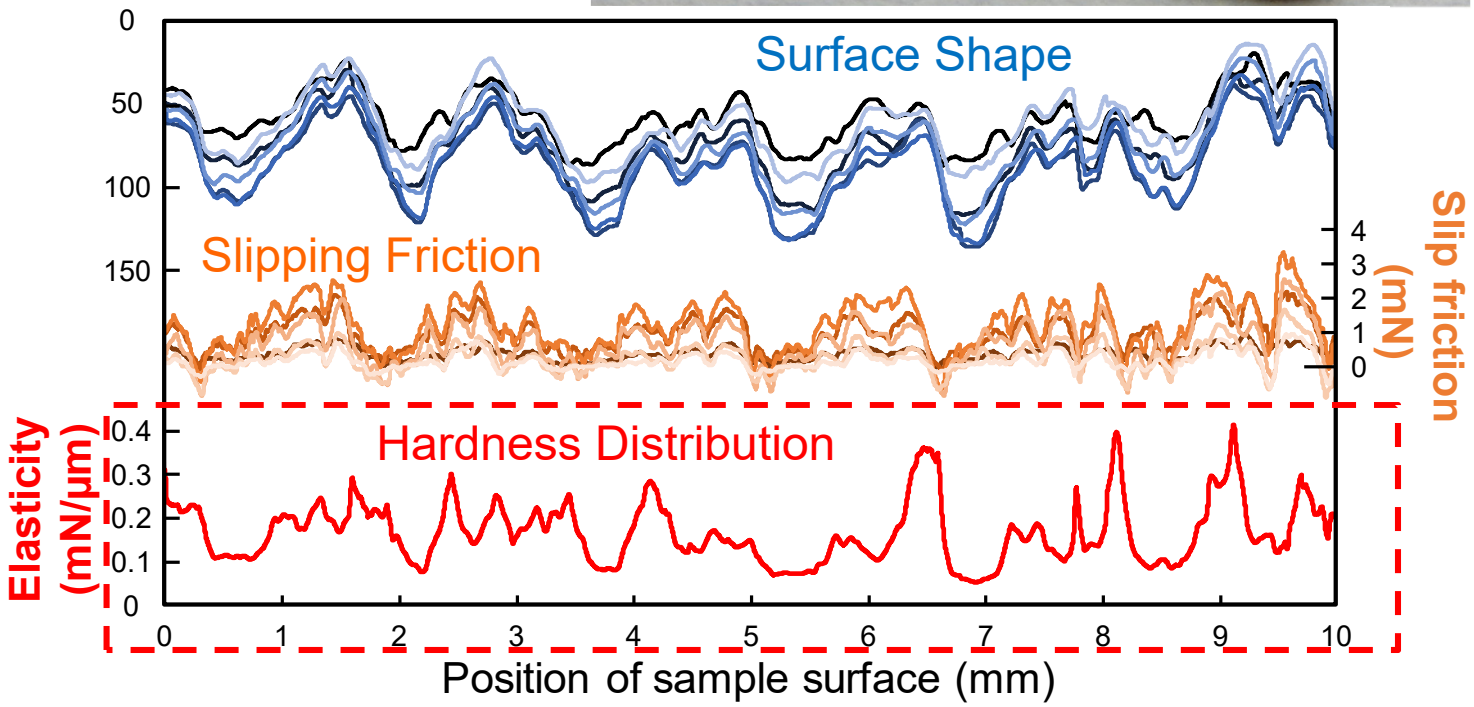

Softer Material



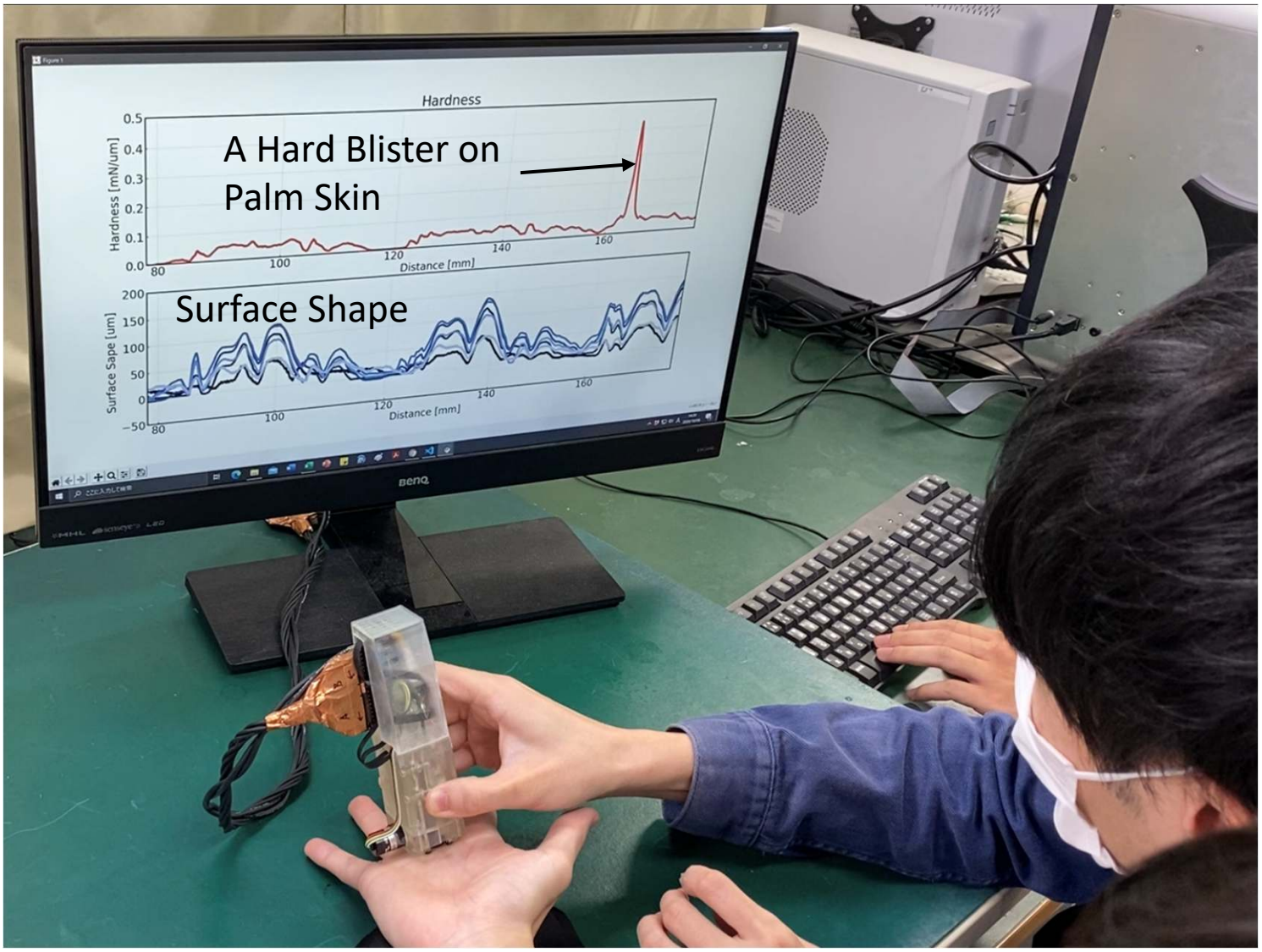
# 100μm-Resolution Elasticity Distribution



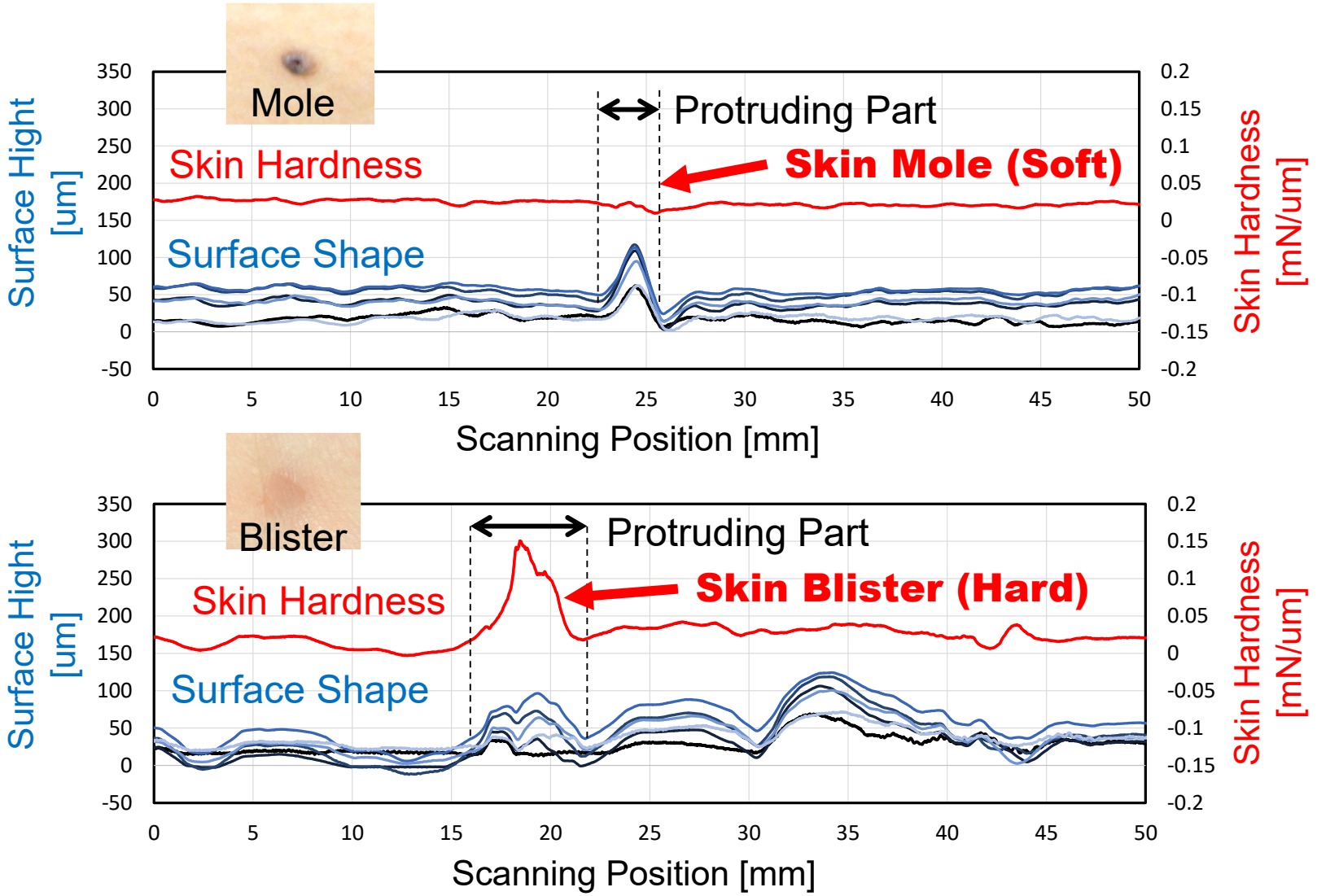



# 2nd-Gen.“Touch-Feeling Scanner”



# Additional Information: Skin Hardness



# Conclusions

**Nano-Tactile Sensor Chip realizes 0.5μm-spatial resolution and below 50μN-force resolution that are the Highest Performances among tactile sensors.**

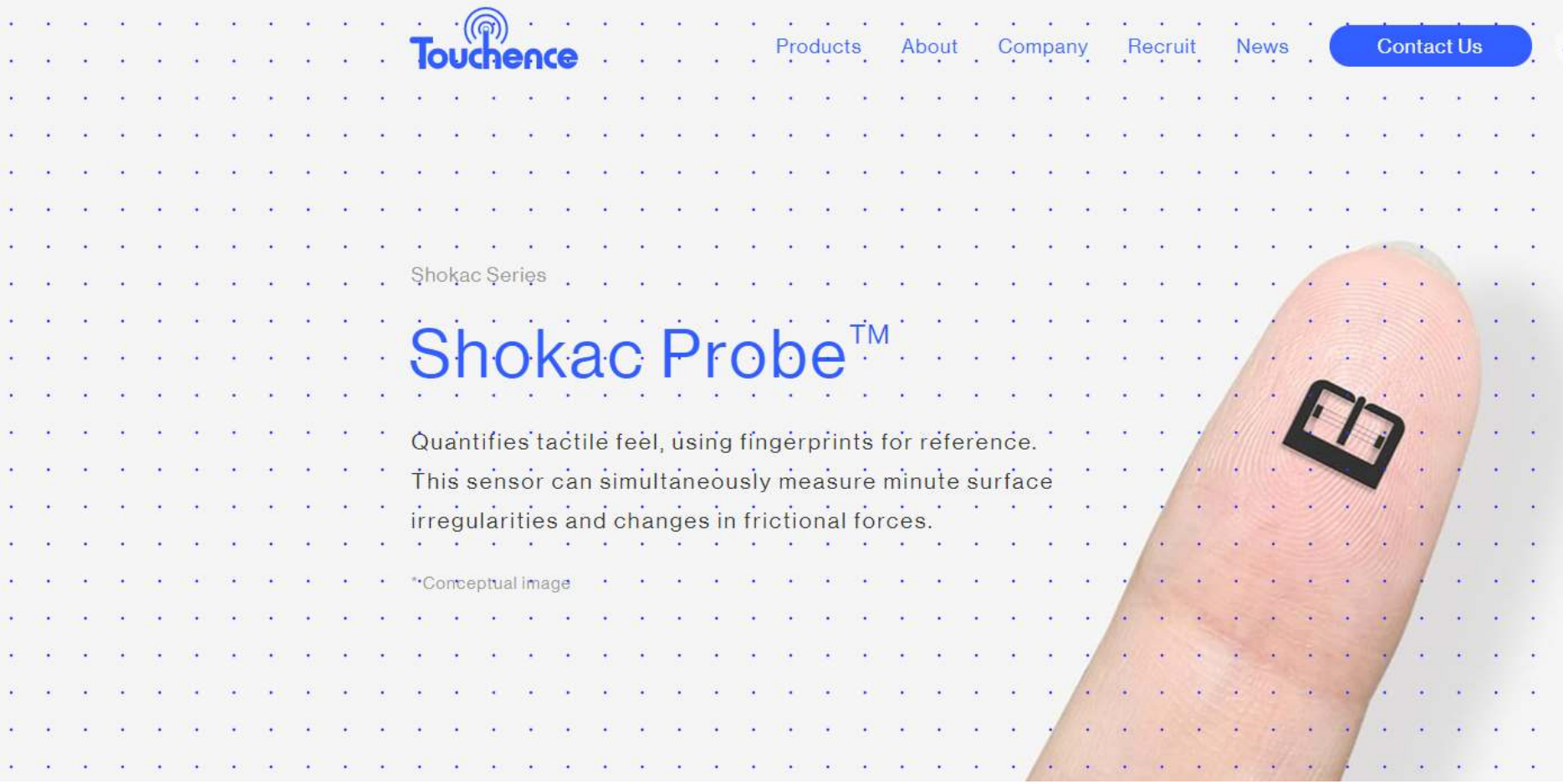
**Combination of Deep N.N. with The Nano-Tactile Sensor Chip has distinguished 7-types of Tissue Papers at 80% accuracy (Human is around 30%).**

**System performance can be more enhanced by Visualized Hardness Distribution at 100μm spatial resolution.**

# “Nano-Tactile Sensor” Will Come in 2022

TOUCHENCE Inc. JAPAN http://touchence.jp/en/

“Shokac Probe” Sensor http://touchence.jp/en/products/probe.html



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- JST CREST (Grant Number JPMJCR20C2)
- JST A-STEP Stage Ⅱ Program
- JSPS KAKENHI (Scientific Research (A)17H01271)

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- Prof. Kinya Kumazawa (JAPN Inst. Invention and Innovation)
- Prof. Yusaku Maeda (National Institute of Tech. Kagawa)
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- All the Staff and Students with Takao CREST Team