Development of an Artificial Fingertip with a High-Sensitivity 3-Axis Force Tactile Sensor Embedded for Robotic Hands

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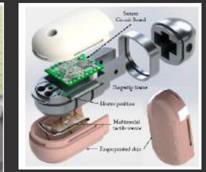
Short resume

Bo-Gyu Bok

Senior Technician

Research interests

I am currently focused on developing tactile sensors that can contribute to enhancing the object manipulation abilities of robots. In addition, I am simultaneously working on methodologies to quantify the tactile sensations experienced by humans, along with the development of tactile sensors for quantification.



Skills

- 2D & 3D CAD design
- MEMS fabrication
- Measurement & Analysis

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Education

(~ 2016)
B.S. Chungnam National University
Chemistry

(~ 2019)
M.S. Yonsei University
Electrical & Electronic Engineering

(~ 2023)
Ph.D. University of Science and Technology
Measurement Engineering

Experience

(2023 - Current)
Senior Technician
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01 Introduction

02 Experiment

03 Sensor Evaluation

04 Summary

01

Introduction

❖ Rationale for Research and Development

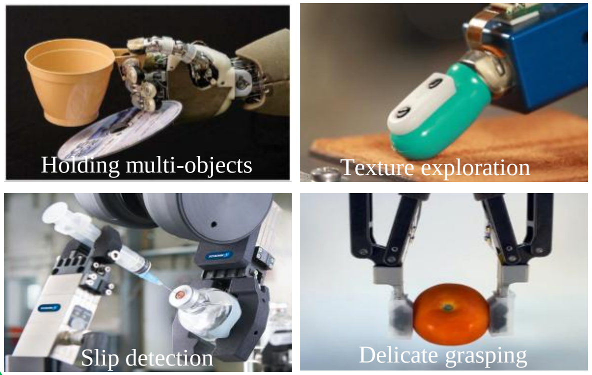
Background

Aging Society & Labor Substitution

High-Risk Environments

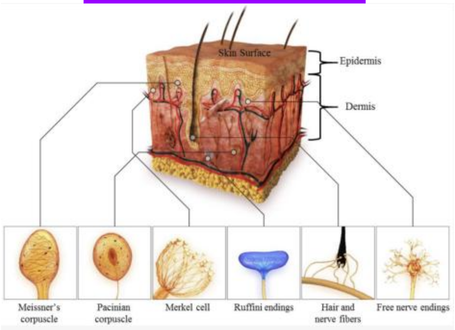
Medical & Domestic Applications

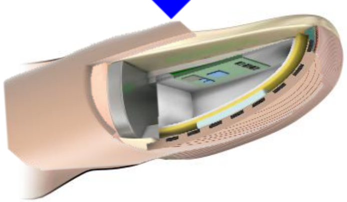
Dexterity in robotics



With the diversification of objects handled by robots, <u>*the demand for dexterity* in robotics is growing</u>

Tactile sensor





Tactile sensors mimicking human touch are gaining attention

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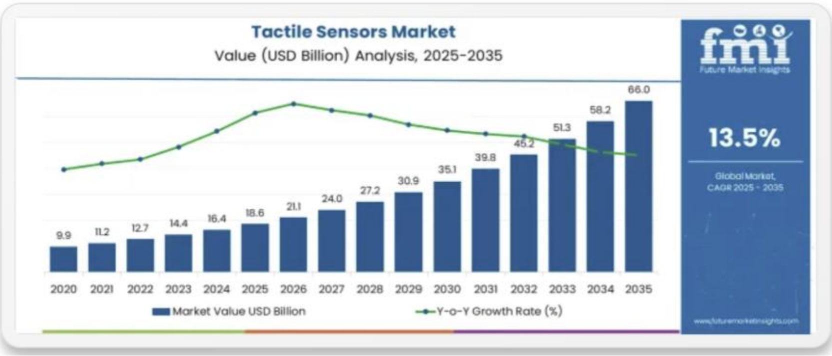
❖ Rationale for Research and Development

Global Market Trends and Development Status of Tactile Sensors

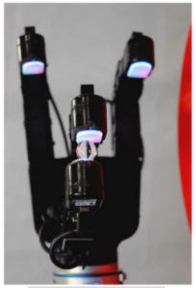


Tactile sensor market forecast (2020-2035)

- Tactile Sensors Market Forecast Value **(2035): USD 66.0 billion**
- Tactile Sensors Market Forecast CAGR: **13.5%**

SynTouch

XELA Robotics

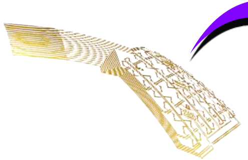


GelSight

AIDIN Robotics

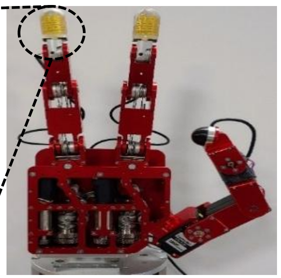
Vulnerability in detecting physical quantities generated at the contact area due to the *absence of a high-sensitivity 3-axis force sensor array*

Our research concept



Flexible tactile sensor array based on Si-NM

Artificial fingertip with tactile sensor



Example Image of the Hand in Integrated State

Development of an Artificial Fingertip Embedded with a High-Sensitivity 3-Axis Force Tactile Sensor Array for Robotic Hands

02

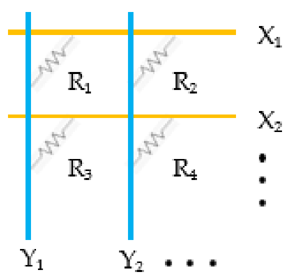
Experiment

02 Experiment

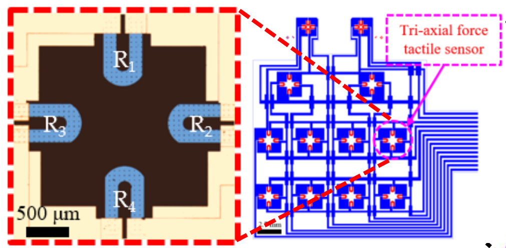
❖ Design & Fabrication

Device Layout

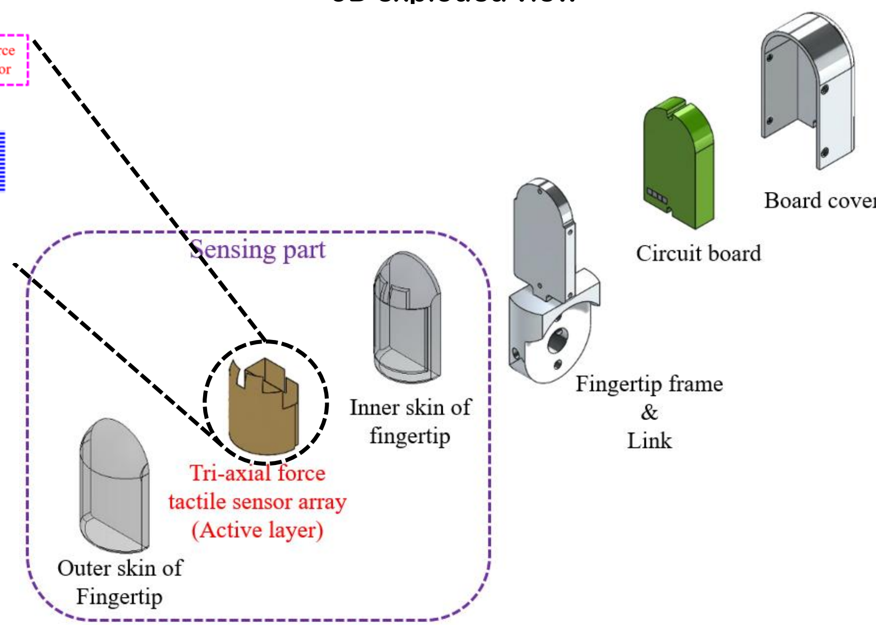
<Circuit diagram>



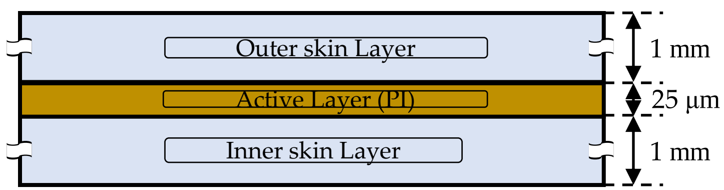
<Sensor image>



<3D exploded view>



<Cross-sectional view & Dimensions>



- We arranged **four horseshoe-shaped** strain gauges based on single-crystal silicon nanomembranes in an NESW (north–east–south–west) arrangement <u>separated by 90° to form a single taxel</u>. → **Total 12 taxels** (<u>Spatial resolution: 1.4 ~ 3.4 mm</u>)
- To minimize the number of signal lines, we implemented **a matrix-type wiring** method with a total of 14 signal lines consisting of eight rows (X) and eight columns (Y) that are used to readout the resistance readings of 48 strain gauges.
- To <u>overcome the disadvantage of inorganic materials</u>, we adopted the strategy, which is **a hybrid structure** where the sensing layer(PI) is placed in between layers of a polymer-based elastomer material (PDMS).

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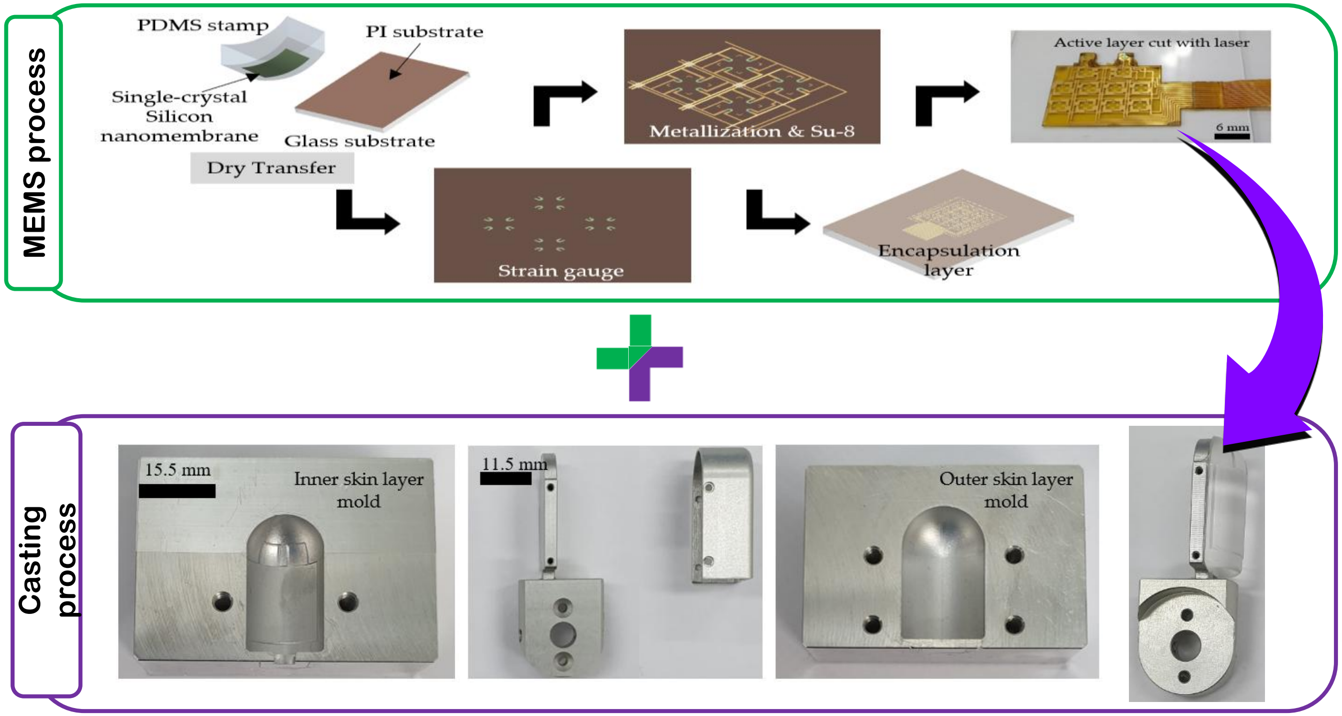
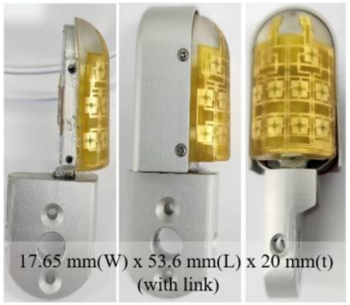
❖ Design & Fabrication

Fabrication process





- The **fabrication process** of our sensing device (which has a hybrid structure) can be subdivided into **two parts**: a sensing layer fabrication process (<u>MEMS process</u>), and the skin layer fabrication process (<u>Casting process</u>).
- We transfer <u>single crystal silicon nanomembrane</u> (100 nm) to PI substrate (25 ㎛) through **Dry transfer technology**.
- The size of the fingertip developed through a series of fabrication processes is <u>17.65 mm(W) x 53 mm(L) x 20 mm(t) (Full size)</u>.

03

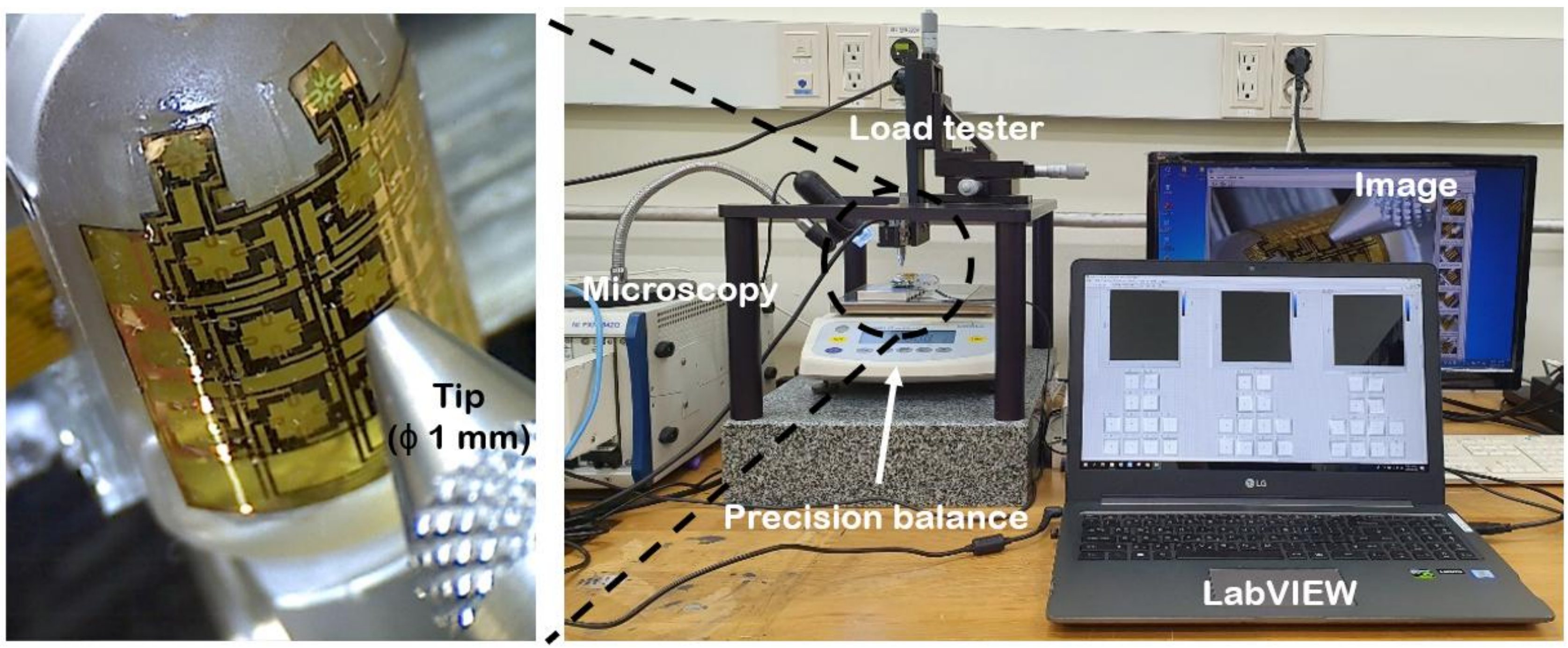
Sensor Evaluation

03 Sensor Evaluation

❖ Performance Tests

Measurement setup

<Tri-axial force measurement setup>



- To evaluate the performance of <u>tri-axial force sensing characteristics</u>, we placed the sensor on a precision balance and applied a load by pressing on the center of the bump using a 1 mm-sized metal tip.
- The sensor signals obtained in the process of evaluation were transmitted to the PC through a circuit board, and these were acquired using the Labview program.

03 Sensor Evaluation

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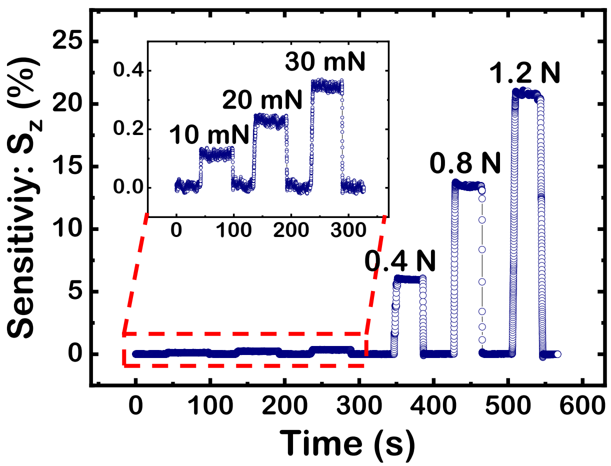
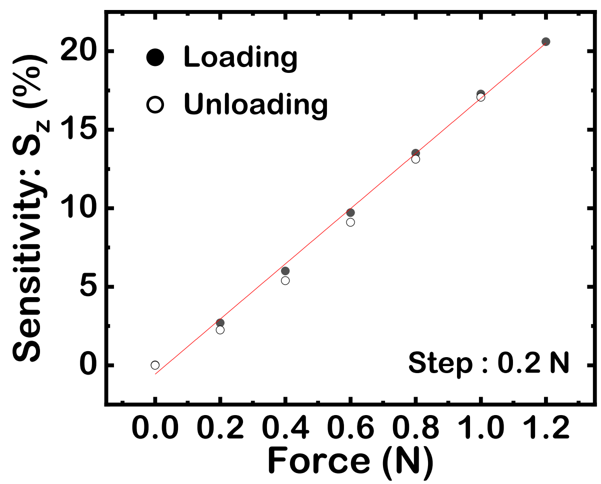
❖ Performance Tests

Mechanical properties (Normal force)

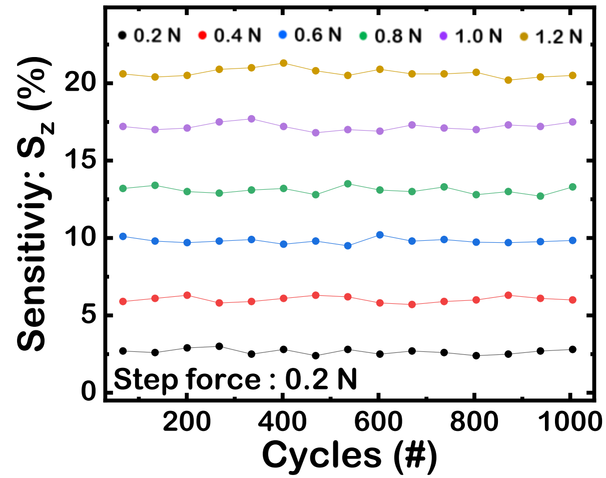
<Normal force data>



<Hysteresis data>



<Repeatability data>



- $F_z = \alpha_Z S_Z = \alpha_Z \left(\frac{1}{4} \left(\sum_{i=1}^{4} \frac{\Delta R_i}{(R_i)_0} \right) \times 100(\%) \right)$
- Hysteresis error = $\frac{S_{z_{Loading}} - S_{z_{Unloading}}}{FSO} \times 100(\%)$
- Repeatability error = $\frac{\sigma_{Sz}}{FSO} \times 100(\%)$

* $\Delta R_i = R_i - (R_i)_0$ * FSO = Full Scale Ouput

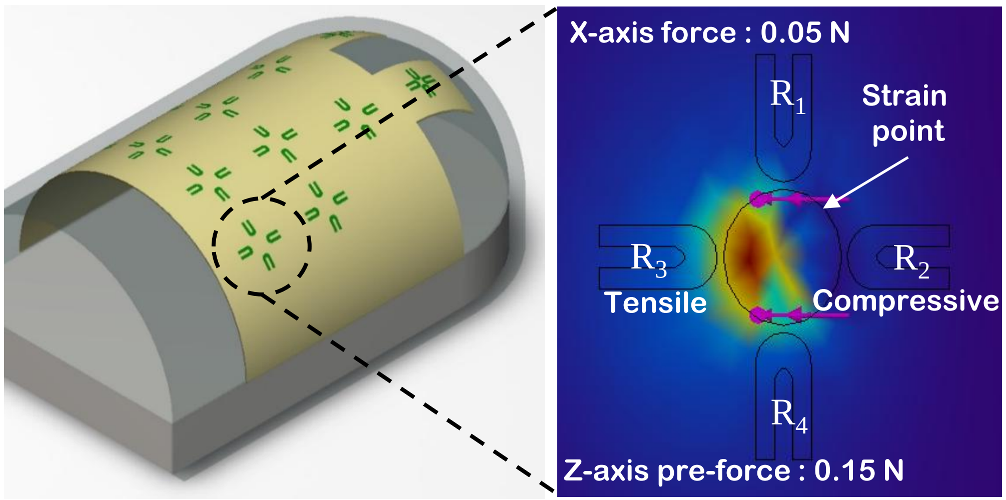
- **Sensitivity coefficient (α_z) : 0.057 %/ N** (R^2=0.997)
- **Sensing range : ~ 1.2 N**
- **Hysteresis error : < 3 %**
- **Resolution : 10 mN**
- **Repeatability error : < 2 %**

03 Sensor Evaluation

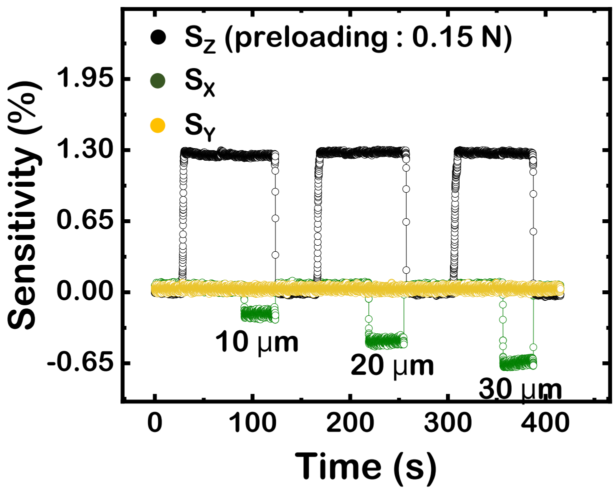
❖ Performance Tests

Mechanical properties (Shear force)

<Sensing principle>



<Shear force data>



- $F_X = \alpha_X S_X = \alpha_X\left(\left(\frac{\Delta R_2}{(R_2)_0} - \frac{\Delta R_3}{(R_3)_0}\right) \times 100(\%)\right)$
- $F_Y = \alpha_Y S_Y = \alpha_Y\left(\left(\frac{\Delta R_1}{(R_1)_0} - \frac{\Delta R_4}{(R_4)_0}\right) \times 100(\%)\right)$

- $E_{xz} = \left|\frac{\Delta S_z}{\Delta S_x}\right| \times 100(\%)$
- $E_{xy} = \left|\frac{\Delta S_y}{\Delta S_x}\right| \times 100(\%)$

* $\Delta S_{x,y,z} = (S_{x,y,z})_{\text{after movement}} - (S_{x,y,z})_{\text{before movement}}$

- **Cross-talk error (E) : < 3 %**

04

Summary

Summary

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➢ We developed an anthropomorphic robot fingertip similar in size to a human finger with a built-in highly sensitive tri-axial force tactile sensor.

➢ The tactile sensor was designed to detect **tri-axial force distribution, and slip** based on a hybrid structure that can have both the high sensitivity characteristics of inorganic materials (Single-crystalline silicon) and the mechanical flexibility of PDMS.

Single-crystalline silicon

- ✓ High gauge factor
- ✓ Greater mechanical & chemical stability
- ✓ Stable sensing performance

PDMS

- ✓ Mechanical flexibility
- ✓ Mechanical properties(e.g., hardness) can be easily controlled.
- ✓ Easy to bond with layers consisting of the same materials.

➢ In the near future, we will demonstrate that it is possible to determine various contact states that occur during object manipulation by analyzing the sensor outputs.

Thank you for your attention!

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