Tactile sensor and its application

April. 24, 2024

Today’s Key Words

- Biomimetics for development of sensor device
- Active sensing to realize improvement of sensitivity, and reduction of unwanted signal
- Multi-sensor system to get more useful information
- Combination of sensor and ***something*** for improvement of sensitivity

Our tactile sense

Somatosensory system

→ Haptic Sense ⇒
- Tactile sense
- Vibration sense
- Temperature sense
- Pain sense

Perception of mechanical and temperature stimuli

→ Deep Sense⇒ (Bathyesthesia)
- Position Sense
- Kinesthetic Sense
- Resistance Sense
- Weight Sense

Perception of state our body and position of parts

→ (Visceral sense⇒ Senses which relate to internal organs)

Smatic receptors spread in our entire body, nonuniformly.
(Especially concentrating on bottom of feet, hands and fingers.)

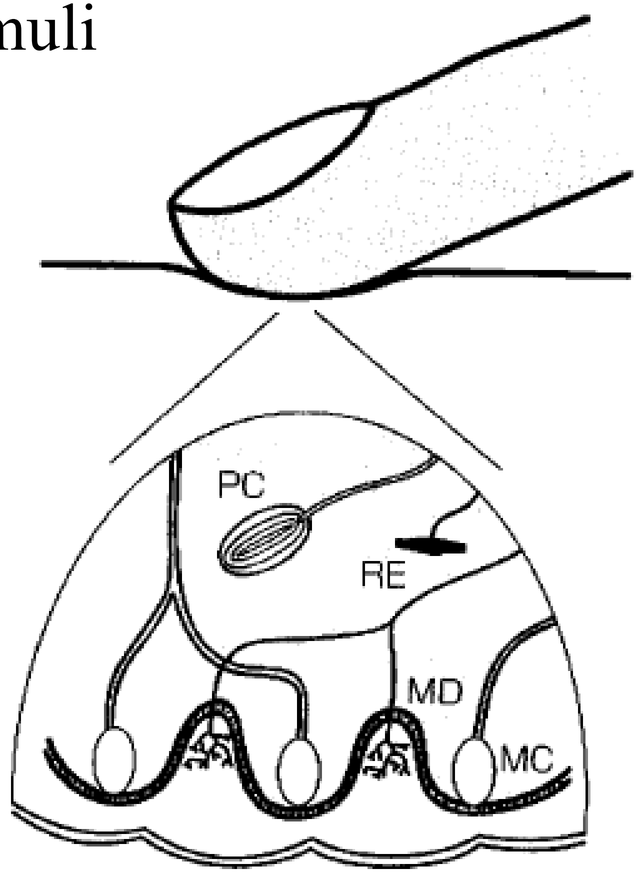
⇓

Sensitivity and sensation are depending upon stimulated position.

Tactile sensor in vivo

Sensors for acquisition of mechanical stimuli

- Meissner's corpuscle：MC
- Merkel's disc ：MD
- Pacinian corpuscle：PC
- Ruffini's end organ：RE



In our intelligent system・・・
Plural sensors with different response property are used for same stimuli.

To analyze complex stimuli in detail.

Fusion of data from sensors with different property, such as sensitivity, dynamic range…etc.

- Development of sensors with different response property

- Using multi-sensor system, and sensor fusion technology

- Sensing method
  - Passive or active sensing

- Signal/data processing to extract useful information from measured data

Tactile Sensors and Applications

- Strain Gage
- Pressure Sensor
- Biomimetic tactile sensor : Carbon Micro Coils : CMC

+ Signal and Data Processing

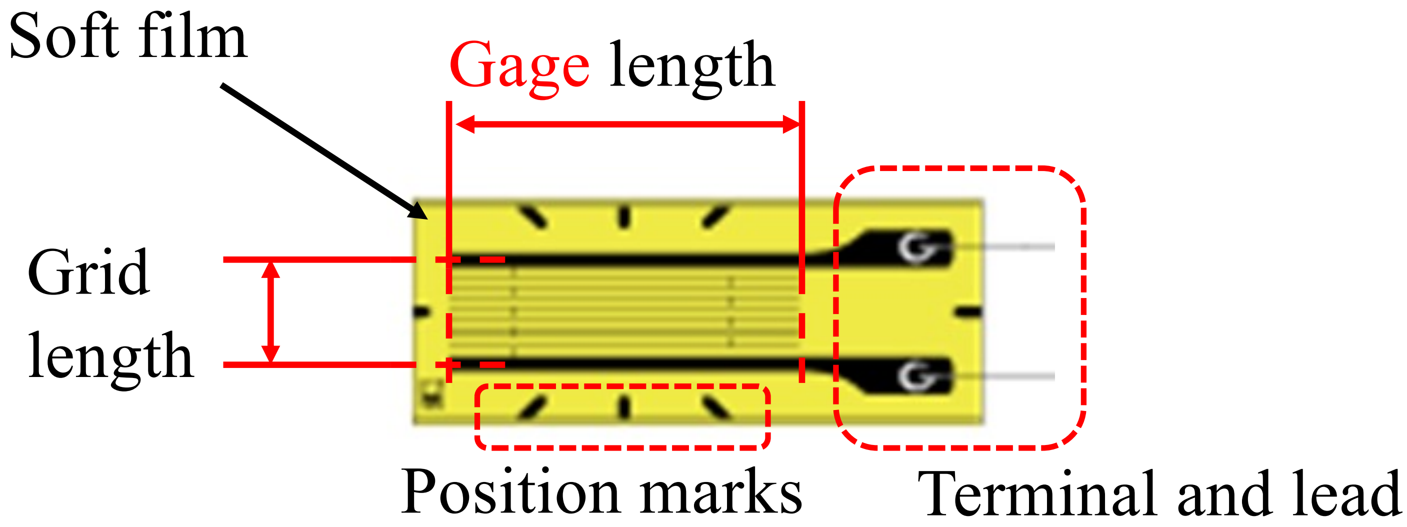
Applications:

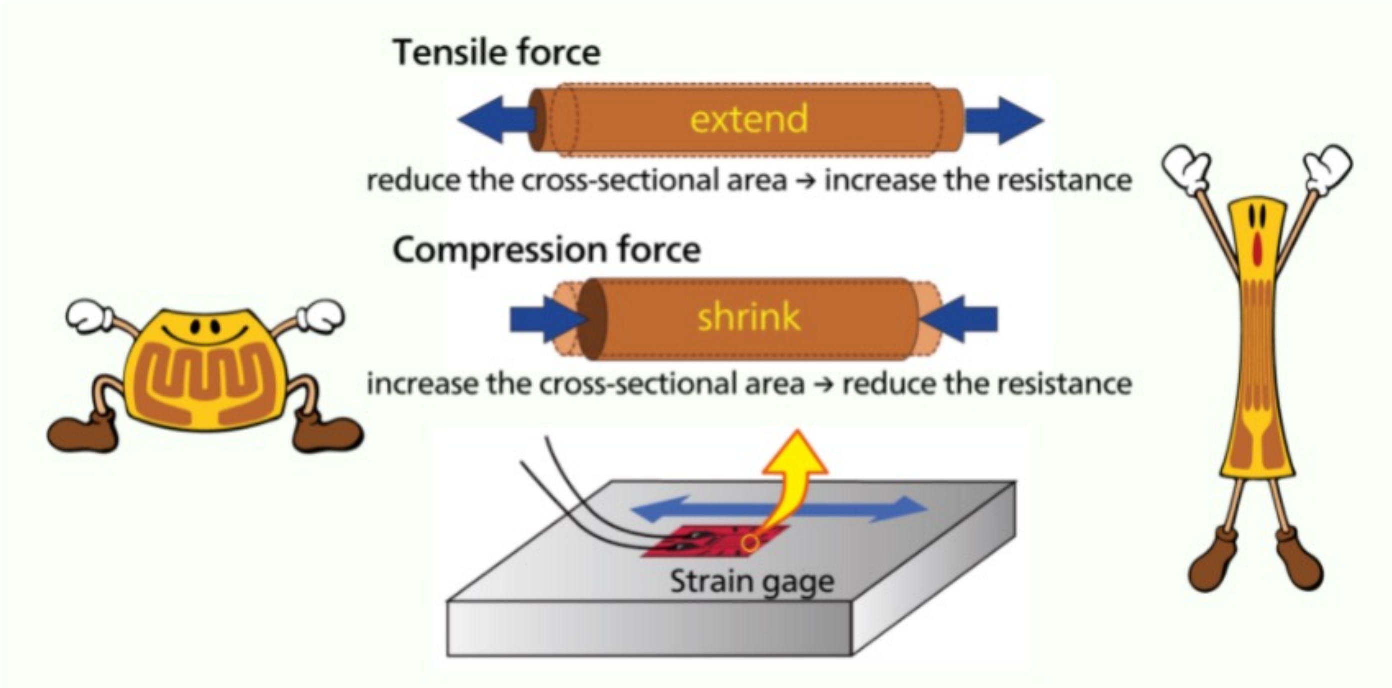
- Artificial Skin
- Objectivization of palpation
  - Evaluation of skin's state
  - Initial diagnosis of breast cancer
  - Evaluation of elasticity of angio
- Objectivization of feel of clothes against our skin

Fundamental tactile sensor

METAL WIRE STRAIN GAGE
AND
SEMICONDUCTOR PRESSURE SENSOR

Metal wire strain gage

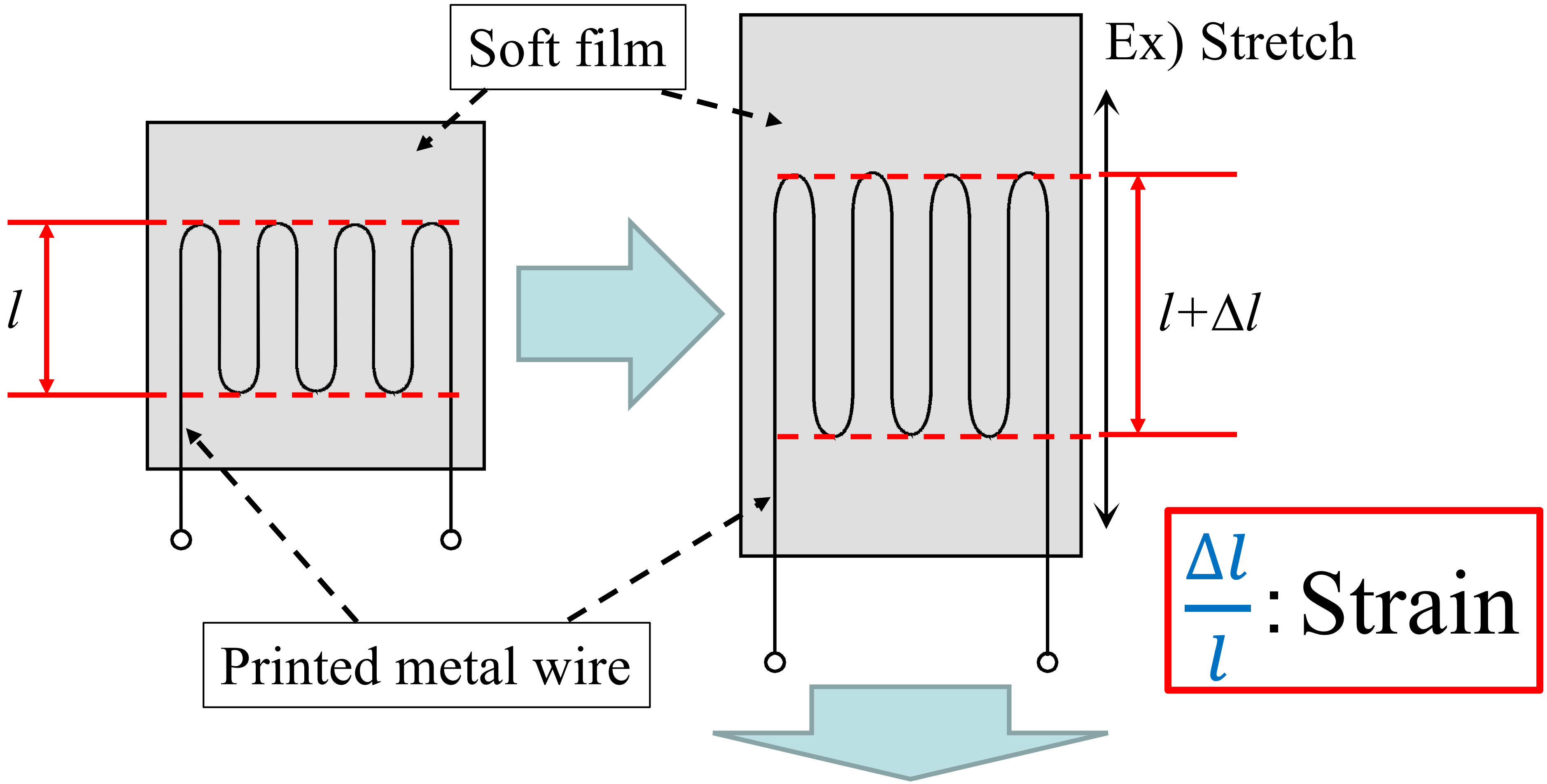




Kyowa Electronic Instruments Co. Ltd.

Metal wire strain gage

When metal wire stretch or shrink. ⇒ Wire resistance changes.



Changes in cross-sectional area and length
of metal wire lead to changes in resistance value

Response of wire strain gage

Resistance of metal wire $R = \rho \frac{l}{S}$

$R[\Omega]$: Resistance of wire, $\rho[\Omega \cdot \mathrm{m}]$: resistivity of material, $l[\mathrm{m}]$: length of wire,
$S[\mathrm{m}^2]$: cross sectional area of wire

Changes in length: Δl
Changes in cross sectional area: ΔS
⇒ Changes in resistance: ΔR

$$
\begin{aligned}
R + \Delta R = R\left(1 + \frac{\Delta R}{R}\right) &= \rho \frac{l + \Delta l}{S - \Delta S} \\
&= \rho \frac{l}{S} \cdot \frac{\left(1 + \frac{\Delta l}{l}\right)}{\left(1 + \frac{\Delta S}{S}\right)} \\
&\cong \rho \frac{l}{S} \cdot \left(1 + \frac{\Delta l}{l}\right)\left(1 - \frac{\Delta S}{S}\right) \\
&= \rho \frac{l}{S} \cdot \left(1 + \frac{\Delta l}{l} - \frac{\Delta S}{S} - \frac{\Delta l}{l} \cdot \frac{\Delta S}{S}\right) \\
&\cong \rho \frac{l}{S} \cdot \left(1 + \frac{\Delta l}{l} - \frac{\Delta S}{S}\right)
\end{aligned}
$$

$$\frac{\Delta R}{R} = \frac{\Delta l}{l} - \frac{\Delta S}{S}$$

The volume of the wire does not change even if Δl and ΔS change.

$$
\begin{aligned}
S \cdot l &= (S + \Delta S) \cdot (l + \Delta l) \\
&= S \cdot l + S \cdot \Delta l + \Delta S \cdot l + \Delta S \cdot \Delta l \\
&\cong S \cdot l + S \cdot \Delta l + \Delta S \cdot l
\end{aligned}
$$

$$S \cdot \Delta l + \Delta S \cdot l = 0$$

$$\frac{\Delta l}{l} + \frac{\Delta S}{S} = 0$$

$$-\frac{\boldsymbol{\Delta S}}{\boldsymbol{S}} = \frac{\boldsymbol{\Delta l}}{\boldsymbol{l}}$$

$$\frac{\Delta R}{R} \cong 2\frac{\Delta l}{l}$$

Change rate of resistance is proportional to strain.

$\frac{\Delta l}{l}$: Strain

Semiconductor pressure sensor

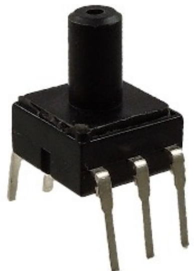


Fig. Semiconductor pressure sensor
（Ref.：Akiduki Denshi Tsusho Co., Ltd.）

The operational principle
⇒ Piezo resistive effect

Applied mechanical load

Changes in inter-atomic spacing in the material

The changes affects
the bandgap of the material.
⇒ Change in resistance value

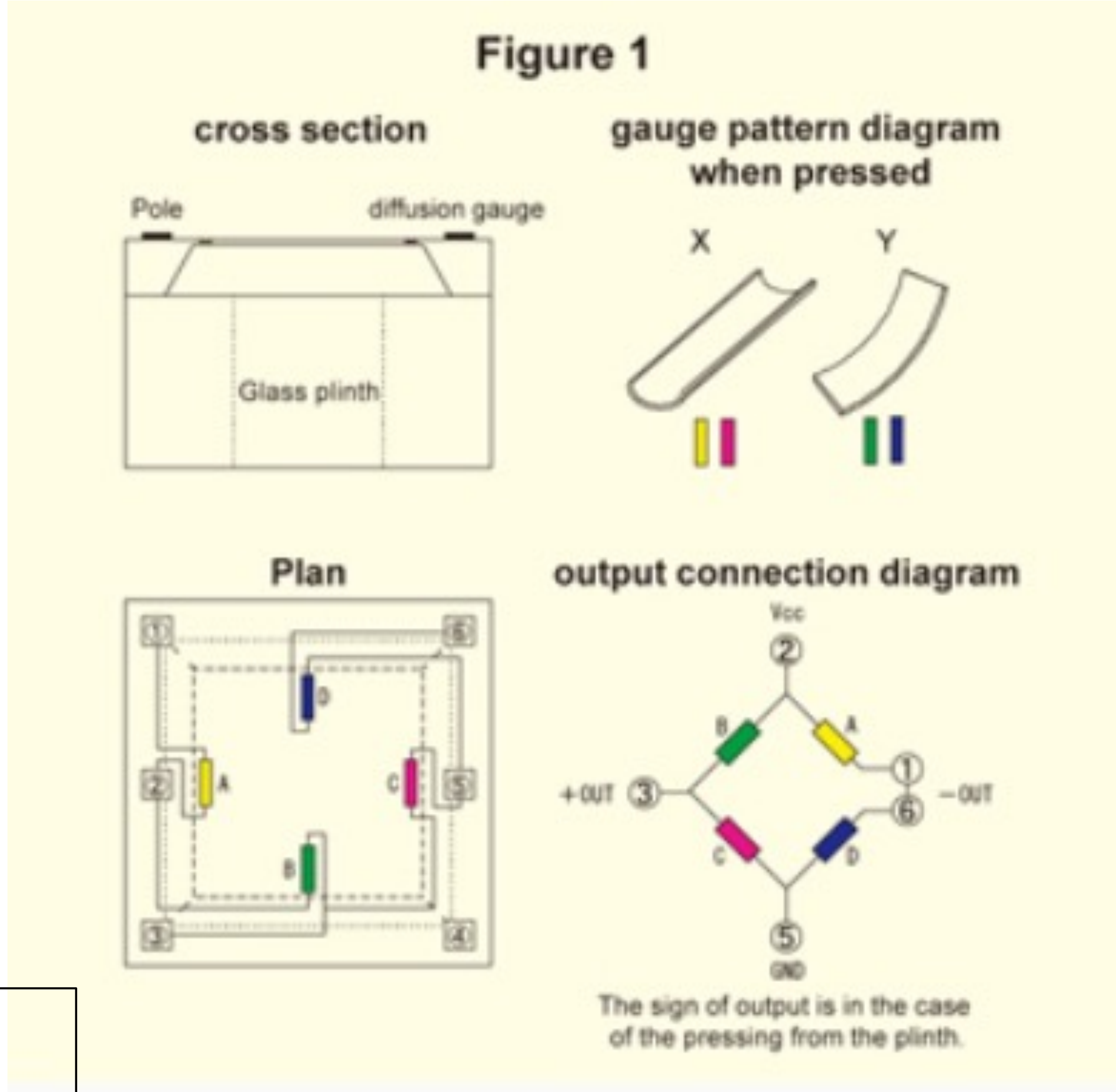


Fig. Sensors structure and its operation.
Ref. Kohden Co., Ltd.

Biomimetic technique in development of sensor device

CARBON **M**ICRO **C**OILS: CMC

High Sensitivity Tactile Sensor using CMC

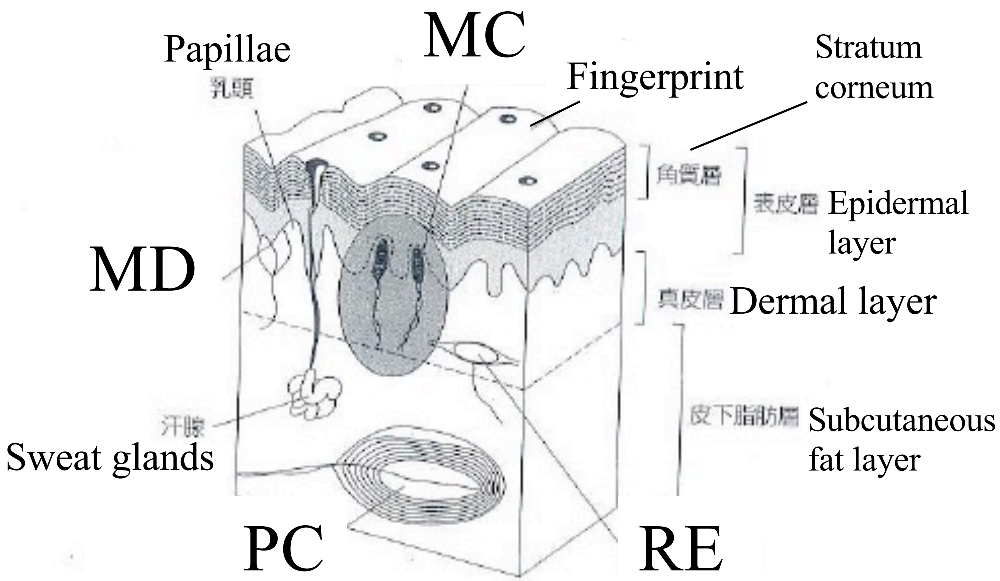
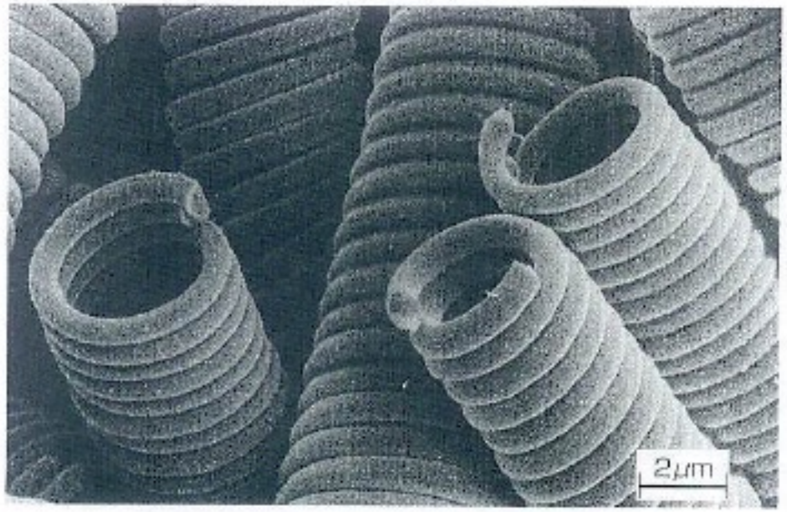
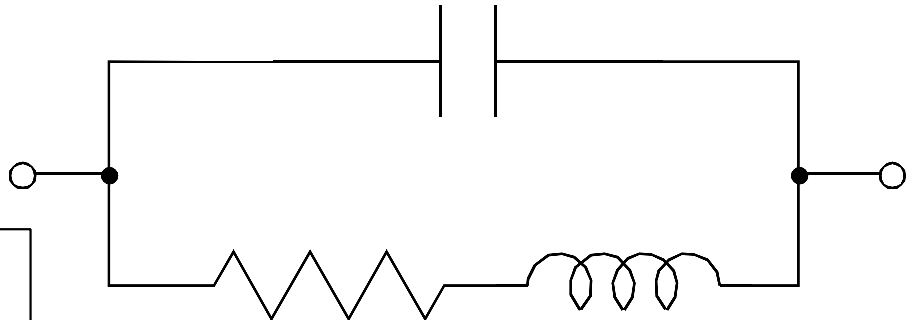


Fig. Human finger pad tissue and tactile receptors



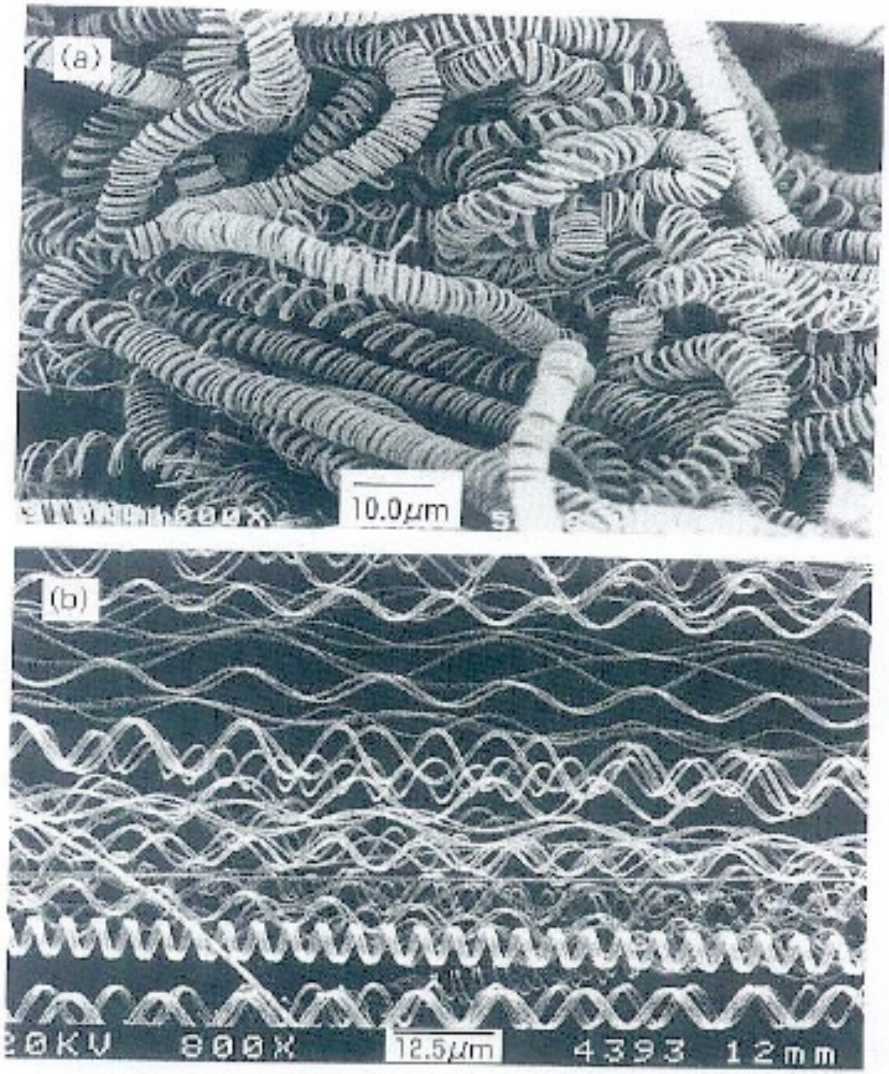
Meissner's corpuscle in vivo
- 3D-helical/helical nerve terminal (protein)
- single helix
- coil diameter: 40 ～ 70μm
- coil length: 20 ～ 150μm

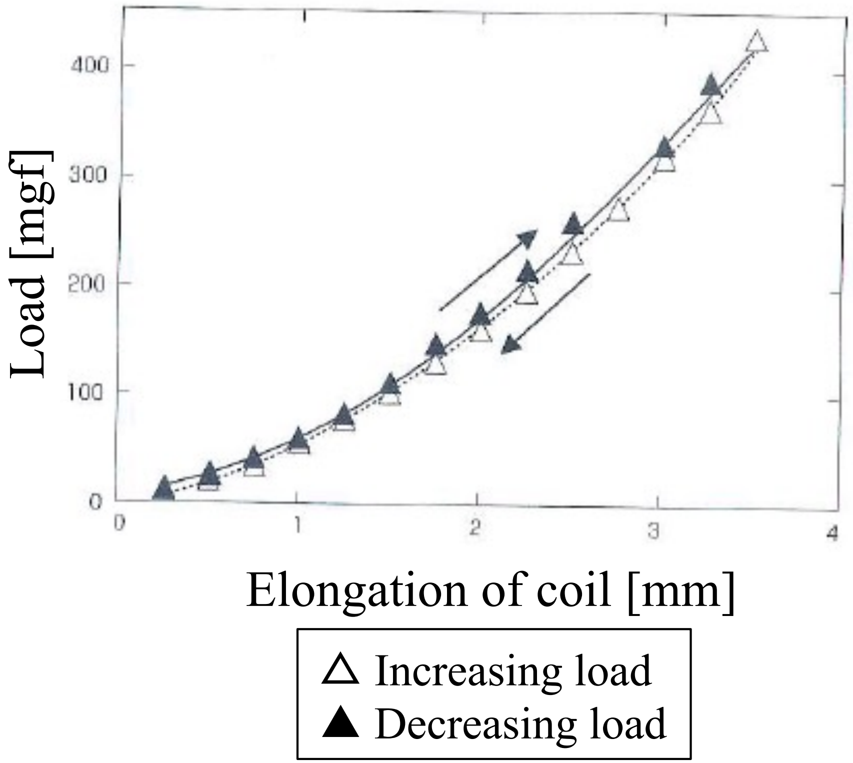
CMC
- 3D-helical/helical nerve terminal (carbon)
- single helix or double helix
- coil diameter: 1 ～ 20μm
- coil length: 50 ～ 500μm



Equivalent Circuit of CMC

Deformation of CMC for its compression and tension



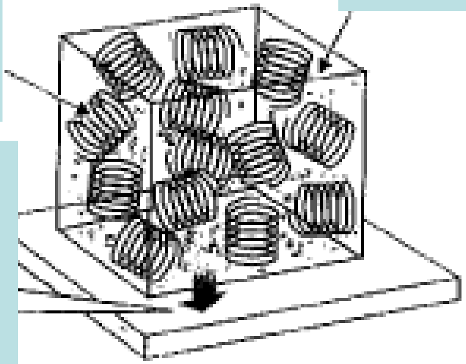


Response of tactile sensor CMC

Spiral Shape CMC

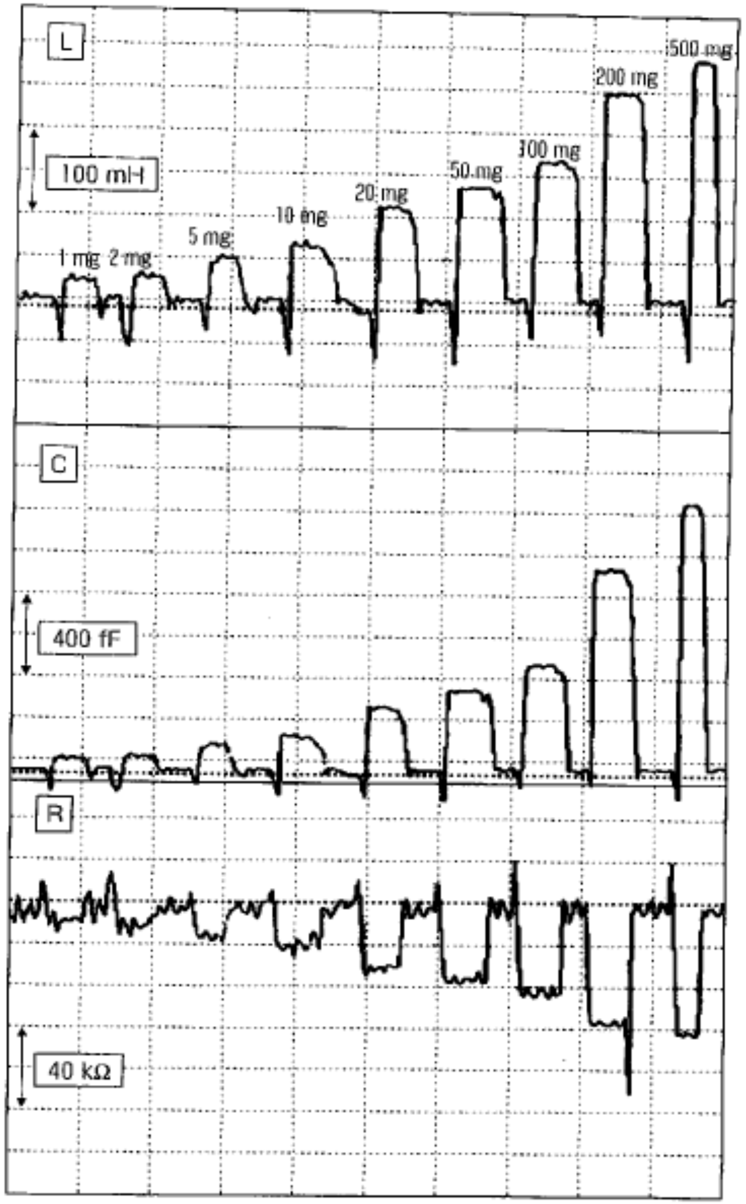
Silicone

Sensor output is caused by Expansion and contraction of CMC by loading of weight to the sensor



High sensitive tactile sensor

CMC Concentration : 1wt% in Silicone.
Sensor Thickness: 100μm



CMC添加量：1 wt%、センサ素子の厚さ：0.1 mm

Application of tactile sensors 1

SKIN STATE SENSOR

Passive or Active Sensing

Passive Sensing : Usual sensing method.
Waiting and Monitoring Stimuli.

Active Sensing : To get the response against input to sensing subject intentionally

In a tactile sense・・・

"Passive Touch" and "Active Touch"

Sensitivity is not same.
Active touch realizes higher sensitivity, because of the relation with Brain (Concentrating our consciousness to object).

Piezo electric effect

Mechanical load to a material
⇒ Strain of the material
⇒ Slight changes of crystal structure due to material deformation
⇒ The position of the positive charge and the position of the negative charge in the crystal deviate from each other.
⇒ Generation of electrical field in the material.

Generation electrical field by Piezo electric effect

Normal state
⇒ Positive and negative charges are centrally located.

Applying compression load
⇒ Changes of positive and negative charges

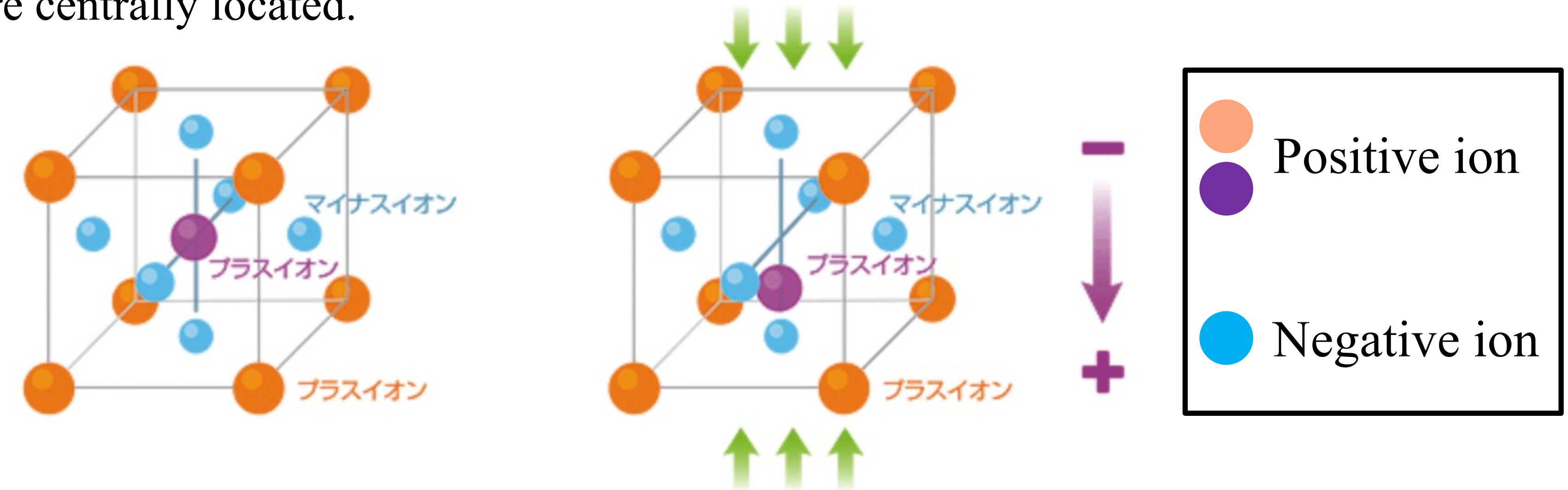
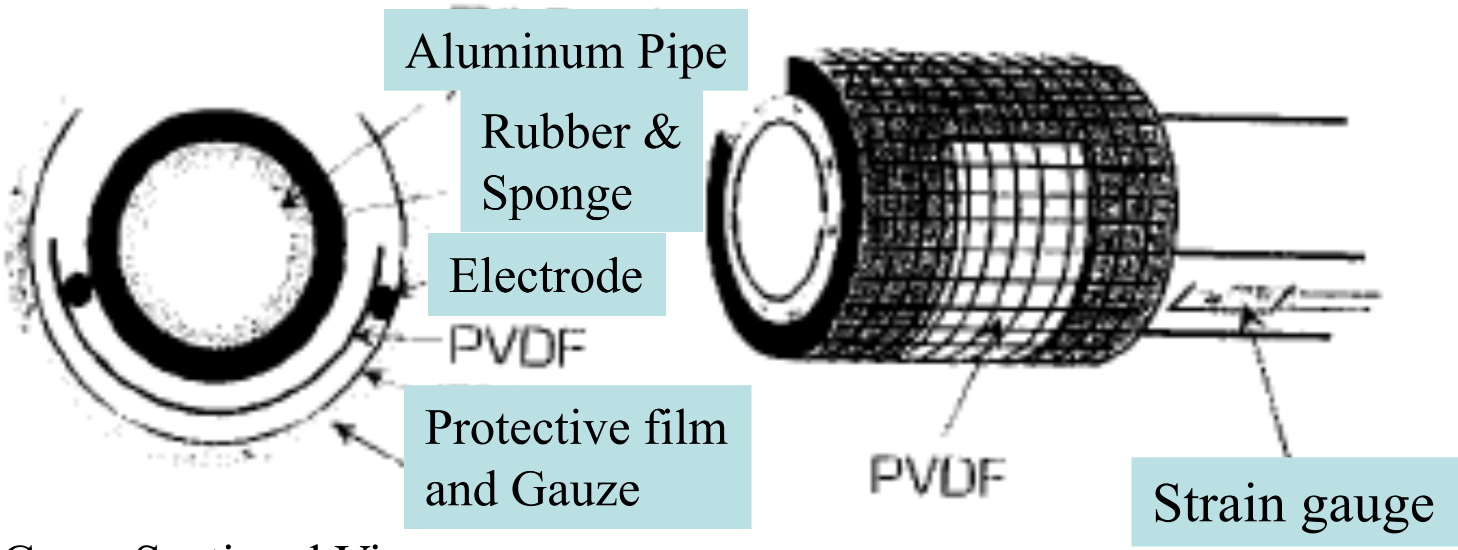


Fig. Piezo electric effect（TDK Co,. Ltd. ）

Sensor for Evaluation of Skin's State using Poly-vinylidene fluoride (PVDF) Piezoelectric pressure sensor



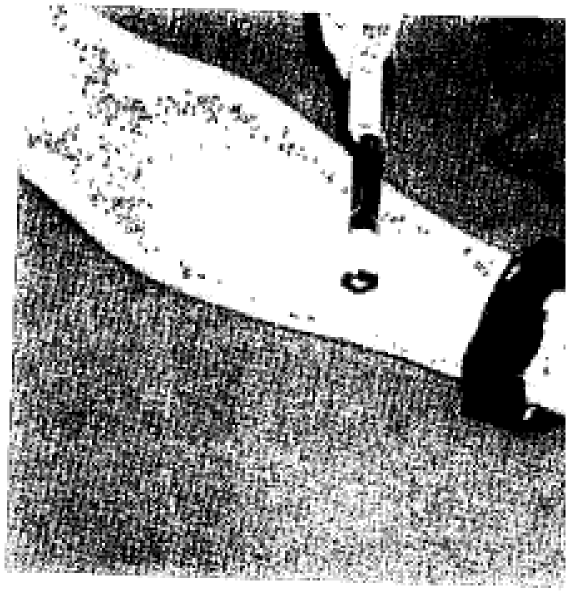
Cross-Sectional View of Sensor

Whole shape of Sensor

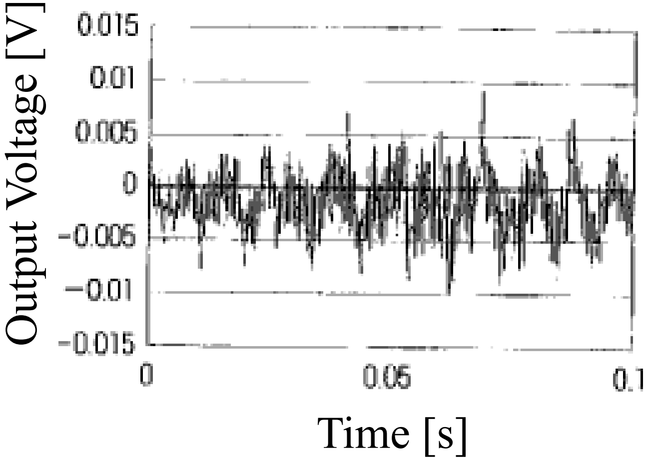
Key point of this method.

- Gauze for the improvement of sensitivity for the roughness.
- Rubber and sponge for the reduction of noise, for the improvement of sensitivity, for the limitation of frequency range of response.
- Strain gauge is used to control touch pressure.

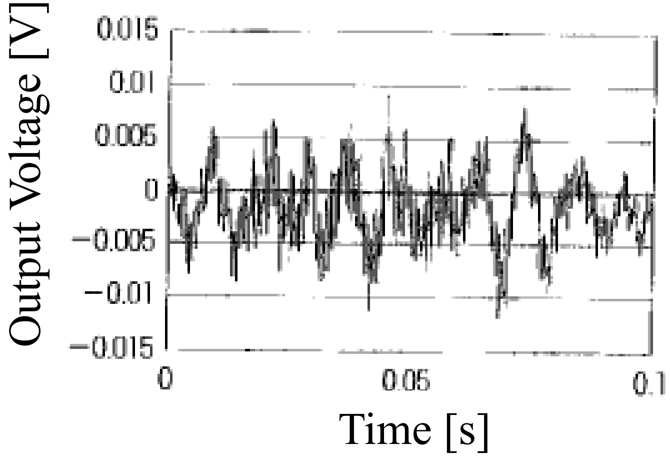
Response of Skin's State Sensor



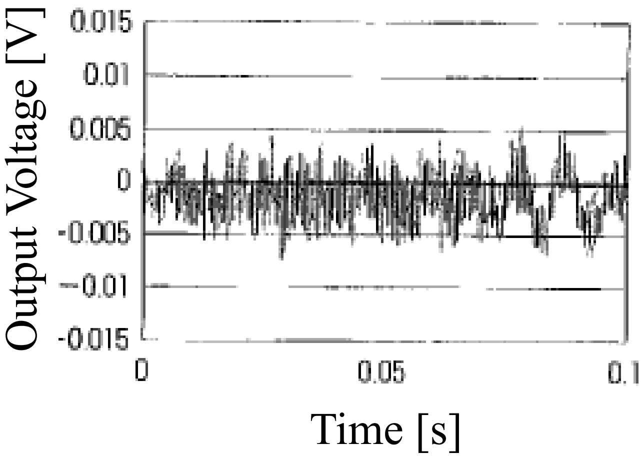
Usage of The Sensor



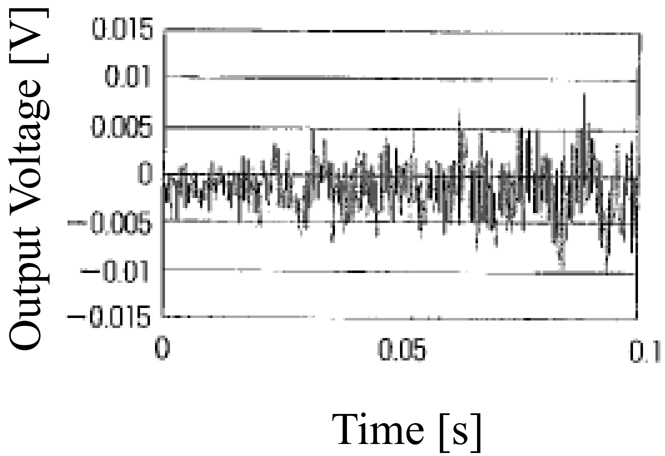
Male 10s



Male 50s



Female 10s



Female 50s

※Vertical Axis: Output Voltage [V], Horizontal Axis: Time [s]

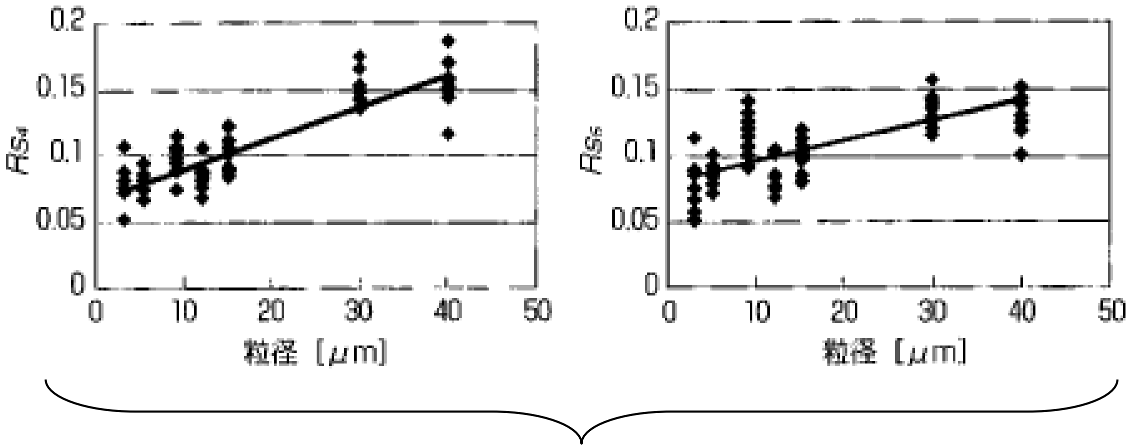
Frequency Analysis for output signal of Skin's State Sensor

Partial Power Spectrum Ratio : $Rs_i = \sum_{A_i} P(k) \Big/ \sum_k P(k)$

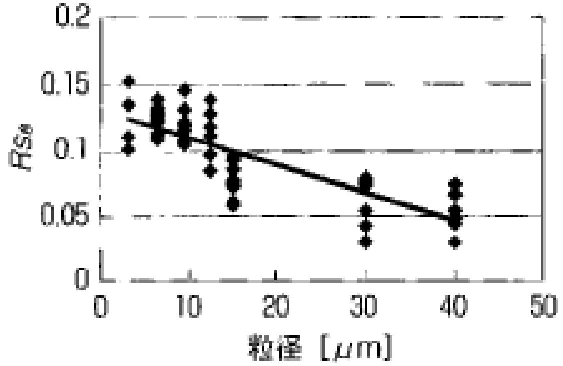
A_i : Frequency Range $\boldsymbol{i}$ $P(k)$: k-th Power Spectrum

表1 周波数領域について

Level	Lv.1	Lv.2	Lv.3	Lv.4	Lv.5	Lv.6	Lv.7	Lv.8
Frequency Range	70 ～ 146	156 ～ 302	312 ～ 615	625 ～ 1,240	1,250 ～ 2,490	2,500 ～ 4,990	5,000 ～ 9,990	10,000 ～ 19,990

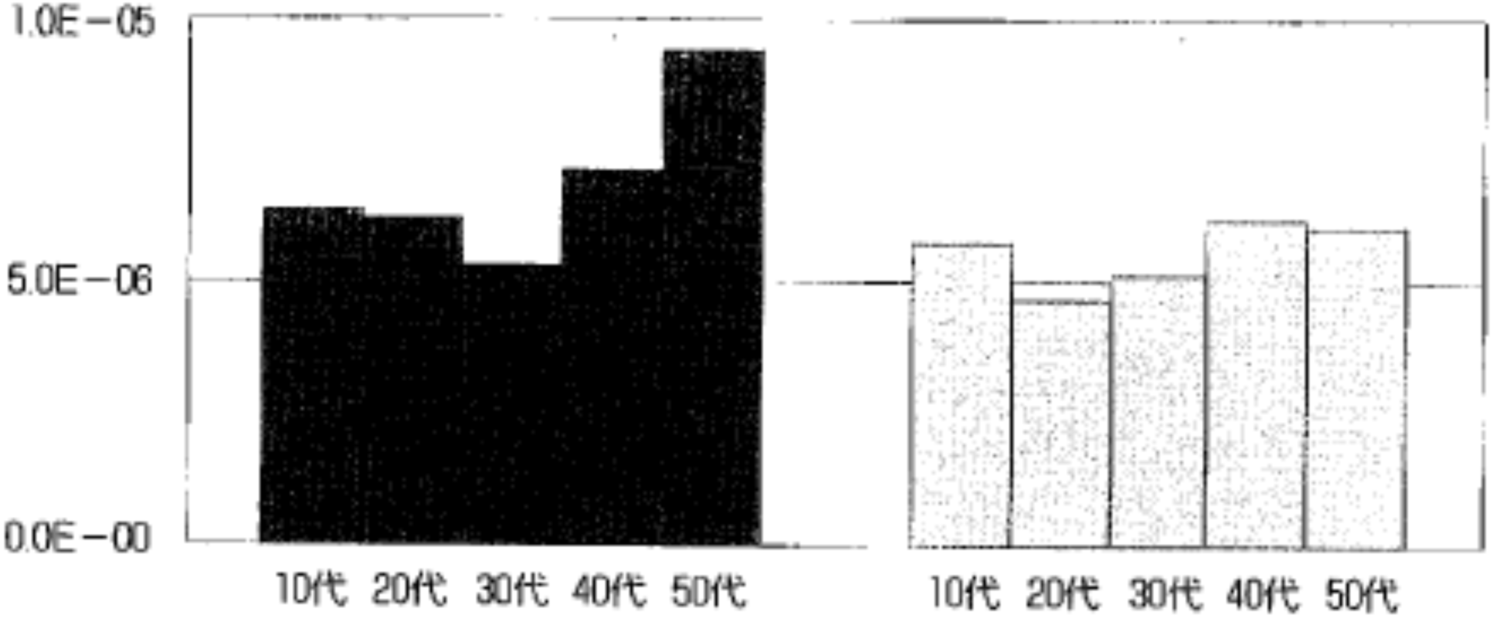


Evaluation of Roughness



Evaluation of Slickness

Evaluation of Sensor Response based on its Variance



Male

Female

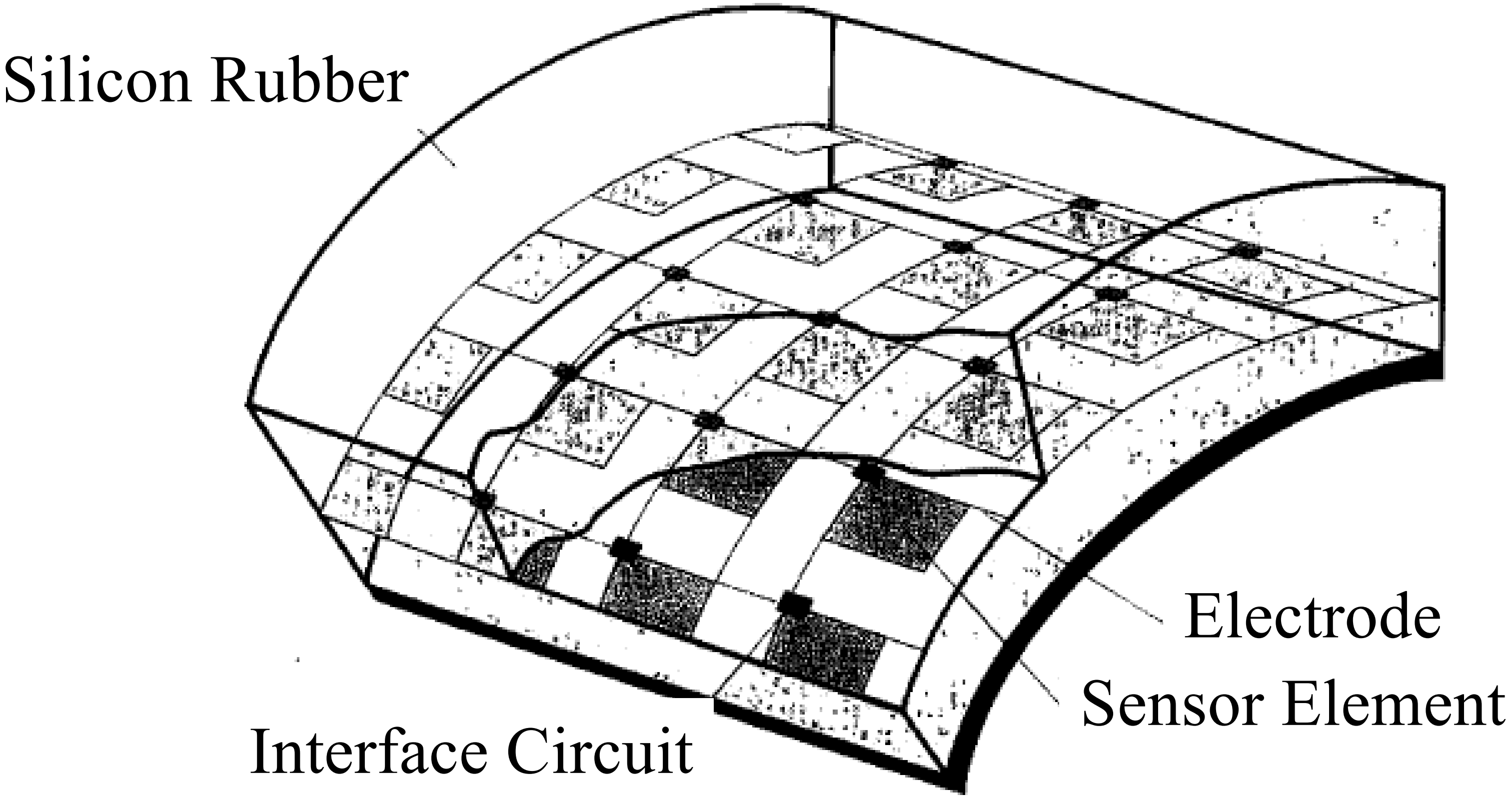
Variance of time series data of output signal is also influenced by Roughness of Skin.

Female’s Variance is stable over a wide age (Why ?)

Application of tactile sensors 2

ARTIFICIAL SKIN

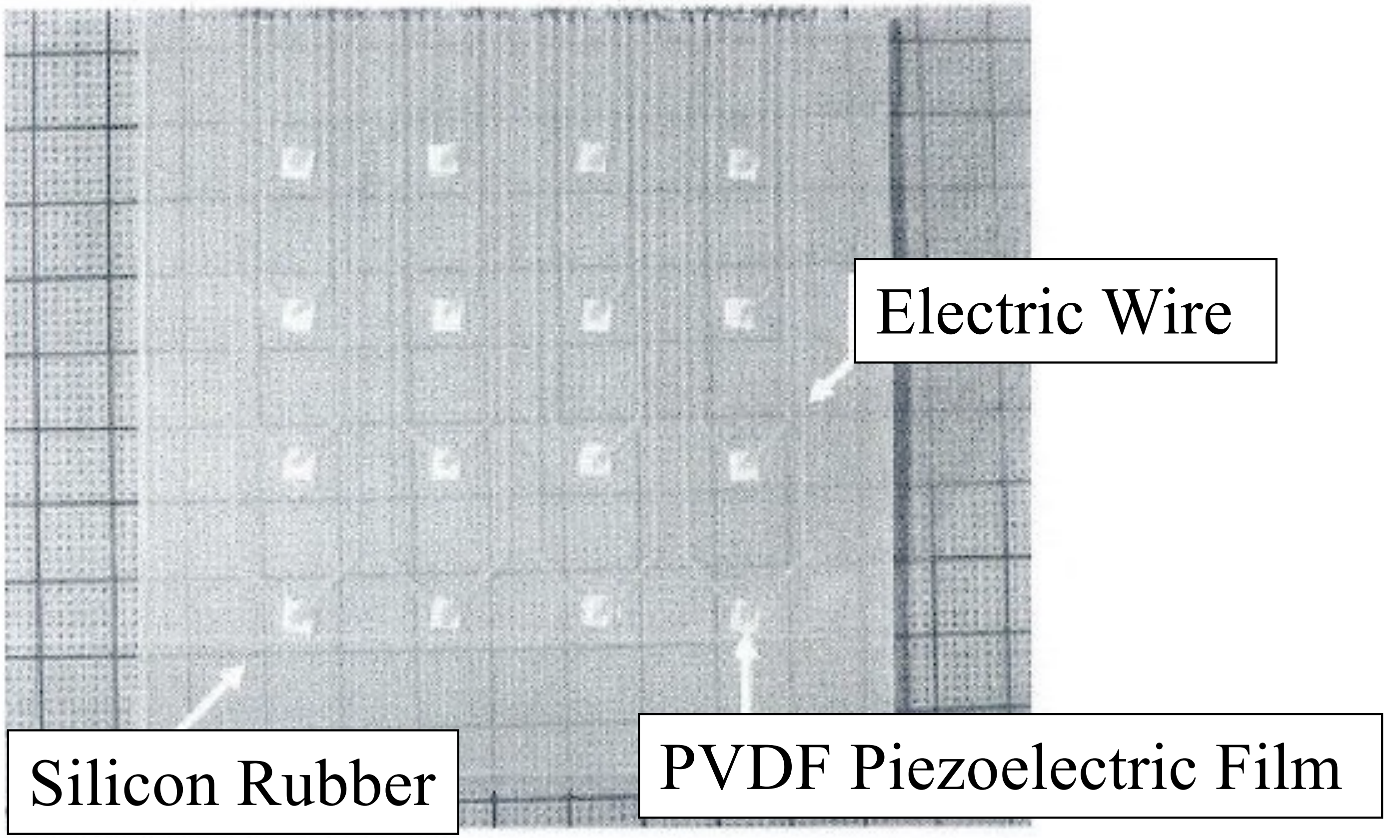
Artificial Skin using Piezoelectric Device



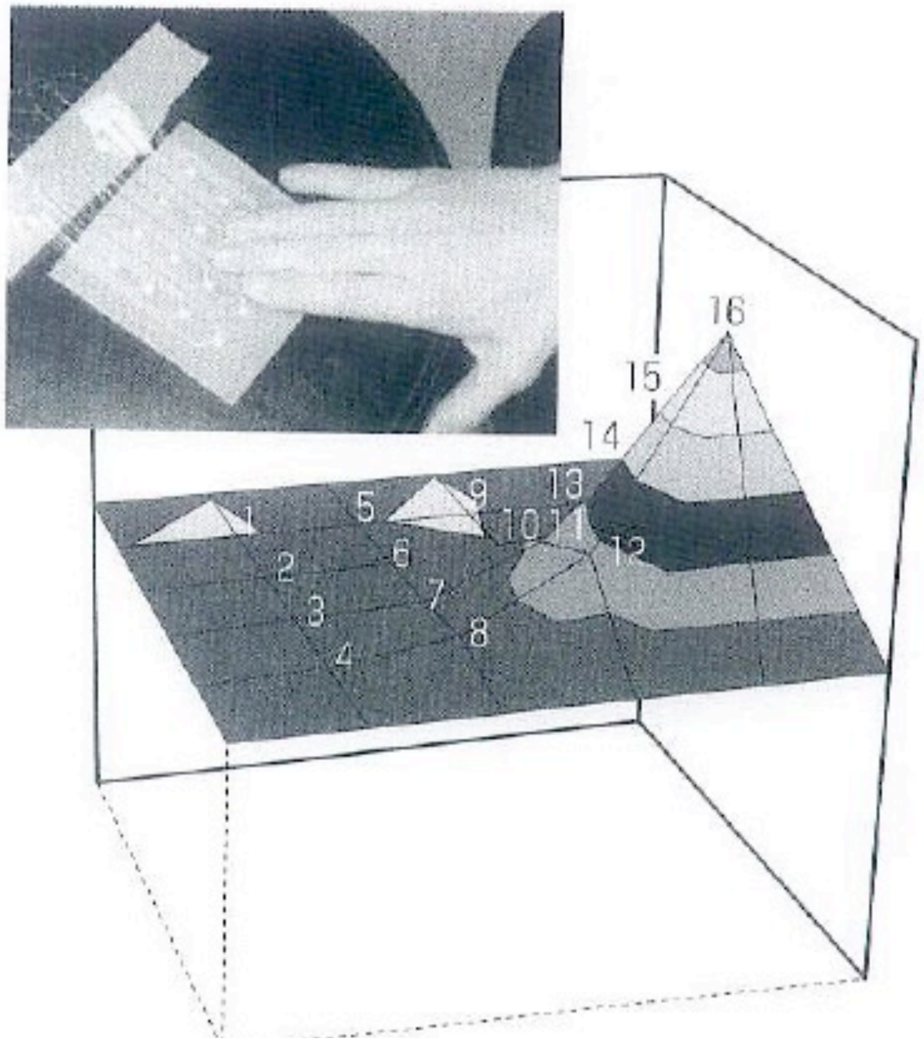
Artificial skin with the function to detect pressure and its area(shape).

Distributed small piezoelectric pressure sensors in silicon rubber

Schematics of Trial Artificial Skin



Response of Artificial Skin for pressure



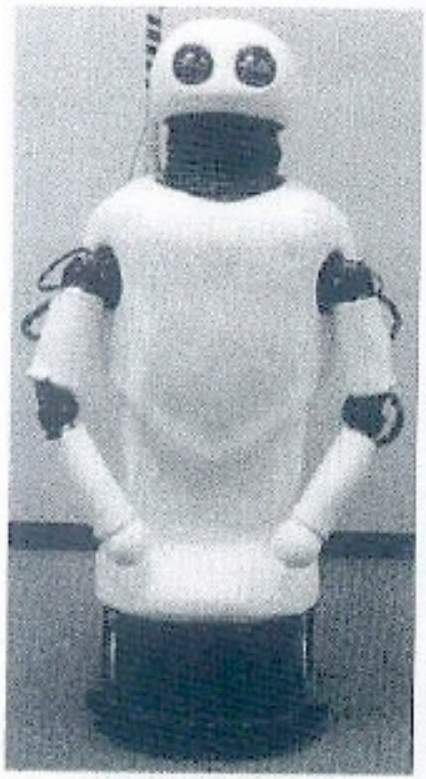
※The number in the graph is indicated the sensor number.

Application as Skins of Robot

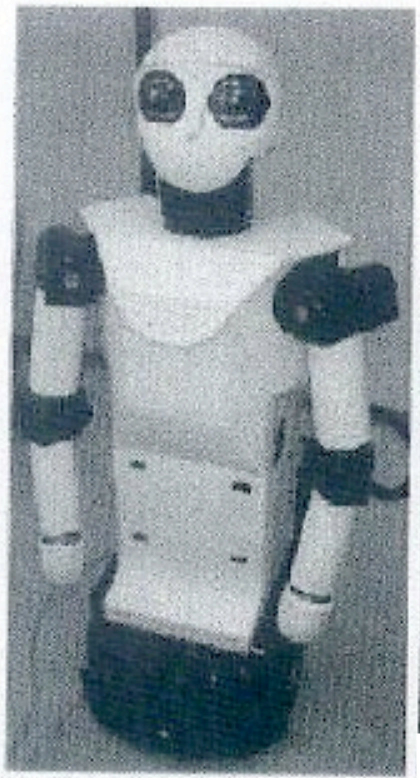
Robot ＋ Artificial skin ⇒ Robot with Tactile Sense

Robovie－IIS

（Intelligent Robotics and Communication Lab in ATR..）



First Version



Second Version

Communication with Children using Artificial Skin

Today’s summary

- Biomimetics for development of sensor device
- Sensor + “something” to improve sensor property
- Support sensor to control active sensing
- Multi-sensor system to get the information about complex stimuli