Tactile Sensing

- Description of touch in human
- Characteristic of touch in human
- Motivation for tactile sensing in robots
- Tactile Sensing on robotic hand
Tactile Sensing

- Description of the touch in humans
- Characteristic of the touch in humans
- Motivation for tactile sensing in robots
- Tactile Sensing on robotic hand
Touch

• What are the physical stimuli for touch?
• What is touch good for?
• What is the sensory apparatus for touch, and how do these structures change touch stimuli into electrical signals (neural firing rates)?
Touch

• What are the physical stimuli for touch?

• What is touch good for?

• What is the sensory apparatus for touch, and how do these structures change touch stimuli into electrical signals (neural firing rates)?
Touch

– Touch refers to the sensations caused by mechanical displacement of the skin
– Perception of temperature changes
– Sensation of pain
– Kinesthesia – Proprioception (limb positions, tendons strength, …)

SOMATOSENSATION
Touch

• What are the physical stimuli for touch?
• **What is touch good for?**
• What is the sensory apparatus for touch, and how do these structures change touch stimuli into electrical signals (neural firing rates)?
Touch

• What is touch good for?
  – Grasping an object
  – Recognise an object
  – Buttoning your shirt
  – Brushing your teeth

  Touch is useful when we are close to the object
Touch

• What are the physical stimuli for touch?
• What is touch good for?
• What is the sensory apparatus for touch, and how do these structures change touch stimuli into electrical signals (neural firing rates)?
Touch Physiology

- Mechanoreceptors
- Thermoreceptor
- Nociceptor
- Proprioceptor
Touch Physiology

• Mechanoreceptors
• Thermoreceptor
• Nociceptor
• Proprioceptor
Touch Physiology

• Mechanoreceptors

Epiderms

Dermis

Subcutis

Mr Meissner corpuscle
MI Merkel cell
R Ruffini ending
P Pacinian corpuscle
Mechanoreceptors

Merkel cell: Slow rate of adaptation, small size of receptive field

respond best to fine spatial details and are especially important in texture and pattern perception.

...reading Braille
Mechanoreceptors

Ruffini ending: Slow rate of adaptation, large size of receptive field

respond to sustained downwards pressure, and particularly to lateral skin stretch, which occurs when you grasp an object.

...picking up a cup of tea
Mechanoreceptors

Meissner corpuscles: Fast rate of adaptation, small size of receptive field respond to low frequency vibration (3-40Hz).

…the cup of tea is slipping across your fingers
Mechanoreceptors

Pacinian corpuscles: Fast rate of adaptation, large size of receptive field respond to high frequency vibration (40-500Hz).

…when you are writing on a piece of paper.
Mechanoreceptors
Touch

![Graph showing mean threshold (mm) for different body parts comparing left and right sides.](image)
Touch Physiology

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SOMATOSENSATION

THERMORECEPTORS

NOCICEPTORS

KINESTETIC RECEPTORS

MUSCLE SPINDLES

GOLGI TENDONS
From skin to brain

• Axons of various tactile receptors are combined into single nerve trunks
• There are many somatosensory nerve trunks, arising hands, arms, feet, legs,…
• There are axons synapse in the spinal cord.
From skin to spinal cord

Dorsal Column Medial Lemniscal
(Fibers Aα, Aβ, Aδ)
Touch, Vibration, proprioception

Ventral Spinothalamic pathway
(Fibers C)
Temperature, pain
From spinal cord to the brain

- Dorsal-column-medial-lemniscal pathway (DCML)
  - Wider diameter axons
  - Faster
  - Tactile and proprioceptive information
From spinal cord to the brain

- Spinothalamic pathway
  - The slower pathway
  - Nociceptor and Thermoreceptor
From spinal cord to the brain

(a) Spinothalamic pathway
- Dorsal horn of spinal cord
- Dorsal root ganglion
- Fibers for temperature and pain
- Ventral posterior nucleus of thalamus
- Lateral spinothalamic tract
- To cerebral cortex

(b) Dorsal-column-medial-lemniscal pathway
- Postcentral gyrus of cortex
- Cuneate nucleus
- Gracile nucleus
- Fibers for pressure, vibration, joint, position sense
- Medial lemniscus
Somatosensory Map

- From the thalamus to S1
Somatosensory Map
Somatosensory Map
Tactile Sensing

• Description of the touch in humans
• Characteristic of the touch in humans
• **Motivation for tactile sensing in robots**
• Tactile Sensing on robotic hand
Tactile Sensing in robots

• Detecting contact with the environment
• Safety
• Grasping an object
• Walking/ Crawling
• Cooperative task with humans
Tactile Sensing in robots
Tactile Sensing in robots
Tactile Sensing

• Description of the touch in humans
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Tactile Sensing on robotic hands
Tactile Sensor System

- Transducer
- Signal Conditioning
- Scanning Circuit
- Data Acquisition
- Communication Link

- Amplifiers
- Multiplexers
- Microprocessor
- A/D converter
- CAN Bus
- USB
- ETHERNET
Block dependences

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- Signal Conditioning
- Scanning Circuit
- Data Acquisition
- Communication Link

- Amplifiers
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- USB
- ETHERNET
What we want to minimize?

• Transducer size
• Signal Conditioning components
• Scanning circuit components
• Wires
• Bandwidth of the communication link

What we want to maximize?

• Sensitivity of the Taxels (tactile element)
• Spatial Resolution
• # of Taxels
• # of measurements (normal force, shear stress, …)
What we want to minimize?

- Transducer size
- Signal Conditioning components
- Scanning circuit components
- Wires
- Bandwidth of the communication link

Silicon based transducers with Amp embedded on a single chip are under development.

HIGH DENSITY PACKAGING
What we want to minimize?

- Transducer size
- Signal Conditioning components
- Scanning circuit components
- Wires ➡️ MID Technology
- Bandwidth of the communication link

**Molded Interconnect Device**

MID technology is to unite electrical and mechanical functions in a single construction unit.
What we want to minimize?

- Transducer size
- Signal Conditioning components
- Scanning circuit components
- Wires
- Bandwidth of the communication link

FlexRay (Fast CAN 10 Mb/s)

IEEE1355 SpaceWire (100 Mb/s to 1Gb/s)
What we want to minimize?

- Transducer size
- Signal Conditioning components
- Scanning circuit components
- Wires
- Bandwidth of the communication link

Embedded Electronic

Transducer  Signal Conditioning  Scanning Circuit  Data Acquisition  Communication Link

MOUNTED ON A FINGER OR ON A HAND
DLR II Hand 2004

6-axis force sensor custom made with strain gauges and embedded electronic on the fingertip.

Serial communication with PowerPC
Strain Gauges

A mechanical stress produces a variation in the resistance.

The variation in the resistance due to the stress is comparable with the one due to the temperature variation so it is required to do differential measurements.
ON-OFF tactile sensors on the fingers (from 20 to 40).

• 3 identical fingers
• 3-axis force sensor on the fingertip
• Signal Conditioning on the palm
• 10 DOF but 4 DOM

RTR II Hand
ON-OFF Sensor

- They provide only a digital information Contact or Not Contact

Legend
- Isolate layer
- Conductive layer
GIFU HAND III

Based on Pressure Sensitive Ink
Pressure Conductive Rubber
Robonaut Hand

FSR based tactile sensor
Force Sensor Resistor

Force Sensing Resistors (FSR) are a polymer thick film (PTF) device which exhibits a decrease in resistance with an increase in the force applied to the active surface.
Shadow Hand

- Tactile Sensors based on QTC
- Embedded electronic on the fingers

**QTC:**

In QTCs the metal particles never come into contact. They do however get very close. So close that Quantum Tunnelling is possible between the metal particles.
FingerTip Sensor
QTC:

In QTCs the metal particles never come into contact. They do however get very close. So close that Quantum Tunnelling is possible between the metal particles.

PRO:

• Noise Reduction
• Repeatability
MAC HAND

- Four fingered hand
- Twelve degrees of freedom (DOF)
- Tendons driven (4 for each finger)
- Absolute Position Sensors
- Force Sensors
- Tactile Sensors
MAC HAND

- Different Sensors
- Embedded Electronics
- Communication Links
MAC HAND

Force Sensor

- Three axis integrated micro-joystick
- COTS component (micro-joystick)

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output Linearity</td>
<td>1.0 %</td>
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<tr>
<td>X,Y Axis Output</td>
<td>0.85 μV/V/g</td>
</tr>
<tr>
<td>Z Axis Output</td>
<td>0.125 μV/V/g</td>
</tr>
<tr>
<td>Maximum Overload Force</td>
<td>40 N</td>
</tr>
<tr>
<td>Dimensions</td>
<td>10 × 7.5 × 5.5 mm</td>
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</tbody>
</table>
MAC HAND

Tactile Sensor

• 64 taxels for each phalange etched on flexible circuit
• Pressure conductive rubber based transducer
- PIC18F458 microcontroller
- CAN BUS Link
They are investigating on the development of a glove with sensors.
Robot Finger with randomly distributed receptors (Asada 2006)

It is based on PVDF films and strain gauges embedded on a silicone rubber in a random way on the fingertip.
PVDF

- PVDF is a piezo-electric material
- It generates a voltage in response to applied mechanical stress.
- No constant response
Artificial skin for humanoid robots

Main idea

Architecture
Artificial skin for humanoid robots
Artificial skin for humanoid robots

Capacitive Tactile Sensor

Prototype

Urethane foam
Conductive Fabric
Artificial skin for humanoid robots

**MCU Module**
- MCU
- I2C bus
- CAN bus

**MCU Layout**

**Triangle Module**
- Top view
- Bottom view
- AD7142

**Triangle Module**

**Triangle Layout**
Artificial skin for humanoid robots

Prototype on a flexible circuit
Artificial skin for humanoid robots

Comformability
Artificial skin for humanoid robots

Prototype covered by silicon rubber