sensing & sensors

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Haptic and Tactile Sensors for Planetary Exploration Robots

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Version 5

Haptics, Tactile Sensing:

hap•tic |ˈhaptik|
adjective technical
of or relating to the sense of touch, in particular relating to the perception and manipulation of objects using the senses of touch and proprioception.

ORIGIN late 19th cent.: from Greek ***haptikos* 'able to touch or grasp,'** from ***haptein* 'fasten.'**

tac•tile |ˈtaktl; ˈtakˌtīl|
adjective
of or connected with the sense of touch : *vocal and visual signals become less important as tactile signals intensify.*
• perceptible by touch or apparently so; tangible : *she had a distinct, almost tactile memory.*
• designed to be perceived by touch : *tactile exhibitions help blind people enjoy the magic of sculpture.*

- In robotics, they are used in slightly different context:

  Tactile (sensor): "a device that measures parameters of a contact interaction between the device and some physical stimuli" [Nicholls and Lee, 1989]

- Main application areas: cutaneous sensors, sensing fingers, soft materials, industrial robot grippers, multifingered hands, probes and whiskers, analysis of sensing devices, haptic perception, processing sensory data

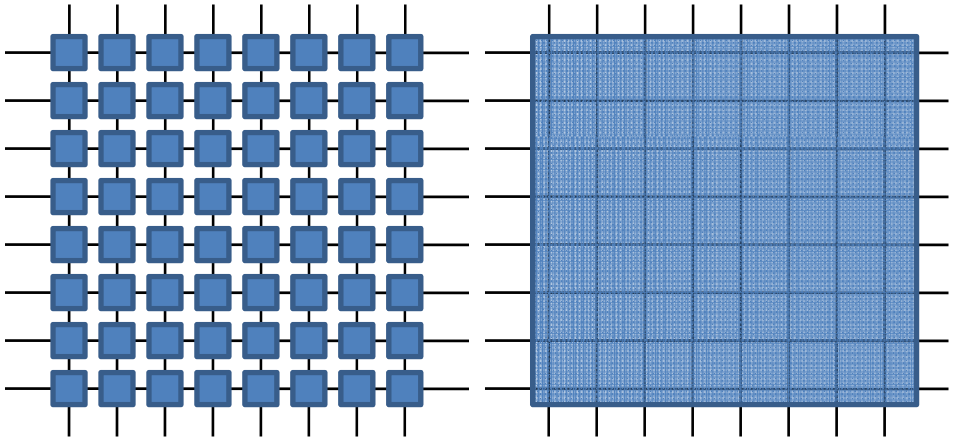
Tactile Sensing:

- What is sensed?
  Deformation of bodies (strain) or fields (electric or magnetic).
  - Through deformations, measure change of parameters, and find:
    - Static texture, local compliance, or local shape
    - Force (normal and/or shear) (*indirect*)
    - Pressure
    - Slippage

- Categories of tactile sensing
  - Simple contact
  - Magnitude of force
  - three-dimensional shape
  - Slip
  - Thermal properties

Tactile sensing: Methods of transduction

- Usually an array of discrete sensing elements or a continuous sensitive medium with discrete sampling.
- Sensing elements can be many types:
  - On/Off: a simple switch
  - Resistive: strain gauge, piezoresistive.
  - Capacitive
  - many other methods (magnetic, piezoelectric, thermal)



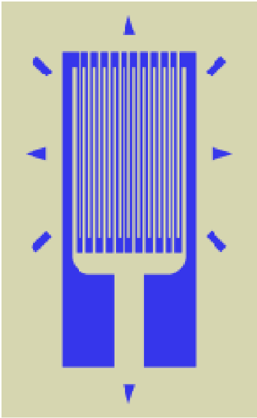
1) Resistance change elements:

- One of the most common.

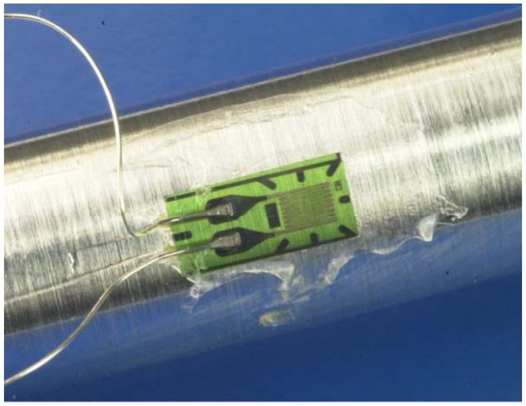
  -Sensing element changes resistance when strained.
- Strain gauge: a thin film with a metal pattern that changes resistance when strained.
- Piezoresistive element.

  Force changes shape = changes resistance

  Resistance change is a result of both geometry change and resistivity change.
- <u>Advantages:</u> very simple, good dynamic range, easy readout, durable,
- <u>Disadvantages:</u> non-linearity, hysteresis, many wires

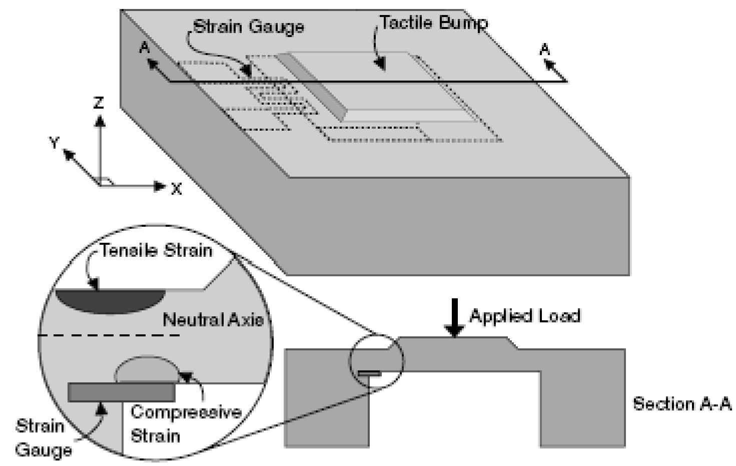


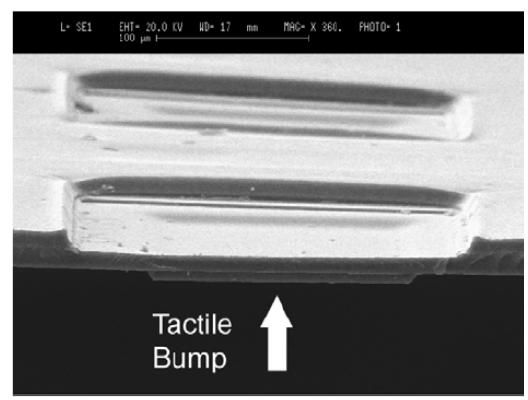
Strain gauge



An example: resistive sensing

- A polyimide based MEMS tactile sensor (10 x 10 array)
  - MEMS diaphragm
  - Strain gauge located where the diaphragm connects to the substrate.
  - 10 μm wide serpentine trace of NiCr in a 100 μm × 100 μm square area.
  - Sensitivity is 0.61 Ω μm^{-1}, with good linearity (R^2 = 0.974).





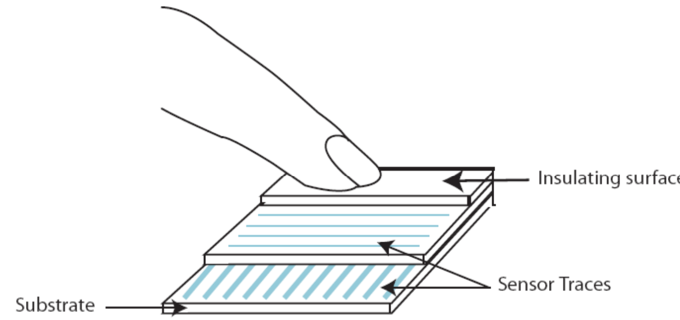
[Engel, *et al.,* “Development of Polyimide Flexible Tactile Sensor Skin”]

2) Capacitance change elements:

- Main application area: touchpad!
- 2 Different sensing methods:
  - Mechanically deform and change the capacitance of parallel conducting plates
  - Or: sense the capacitance change due to stray fields (capacitance is increased)

    Touchpads are tuned to human skin!
- <u>Advantages:</u> good dynamic range, linearity
- <u>Disadvantages:</u> noise, measuring capacitance is hard! (compared to measuring resistance)

http://www.analog.com/static/imported-files/data_sheets/AD7142.pdf



http://www.synaptics.com/sites/default/files/Capacitive_Resistive.pdf

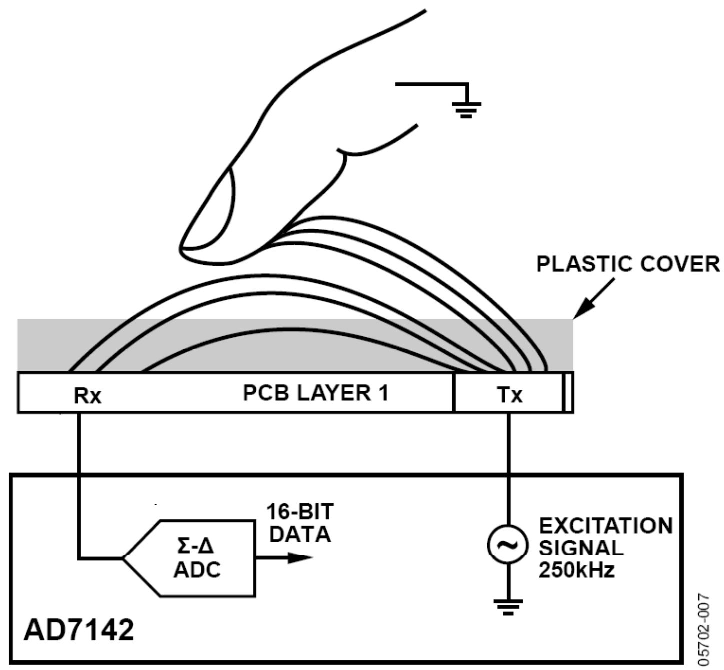
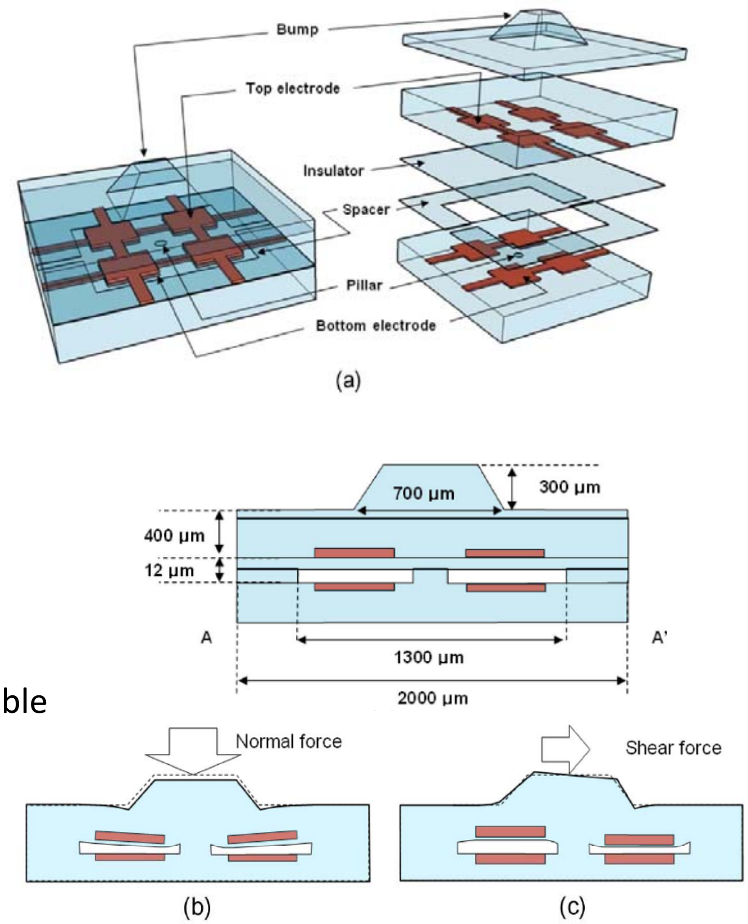


Figure 18. Sensing Capacitance Method

An example: capacitive sensing

- An 8 x 8 array tactile sensor
  - Polydimethylsiloxane (PDMS)
  - Detect force of 10mN, 131kPa in all directions
  - Flexible
  - Sensitivity: 2.5%/mN, 3.0%/mN, and 2.9%/mN for the X, Y, and Z directions, respectively.
  - (why not equal?)

[Lee, *et al.,* “Normal and Shear Force Measurement Using a Flexible Polymer Tactile Sensor With Embedded Multiple Capacitors”]



Other sensing methods:

- Piezoelectric: measure voltage created due to polarization under stress
- Magnetic: use Hall effect to measure change in flux density
- Optical, thermal, others

Assignment

- We have a rectangular resistive block with dimensions L x L x 2L, resistivity **ρ**, young's modulus **E**, and a current source that produces I.
- We want to use this resistive block as a tactile sensor to measure a force, **F**, with the voltage across this resistive block, **V**, being the output of the sensor.
- How would you align the block with respect to the applied force, and which faces of the block would you use to make electrical contacts, so that the absolute value of the sensitivity of the sensor is maximum? What is the maximum sensitivity? (sensitivity = $\Delta V/\Delta F$ in Volts/Newtons)

Some Math for the Assignment

- The resistance of a block is:

  $R = \rho L / A$,

  - ρ = Resistivity
  - L = Length
  - A = Cross sectional Area
- Please assume that the volume of the block does not change.

  (change in one dimension results in change in other dimensions, symmetrically)Assume force is orthogonal to the faces.
- Assume percent change in dimensions is very small
- A block is deformed under force F as:

  $$\Delta L / L_0 = F / (E A_0)$$

  - L_0, A_0 = Original length and cross sectional Area
- And finally:
  - **$V = IR$**

Applications

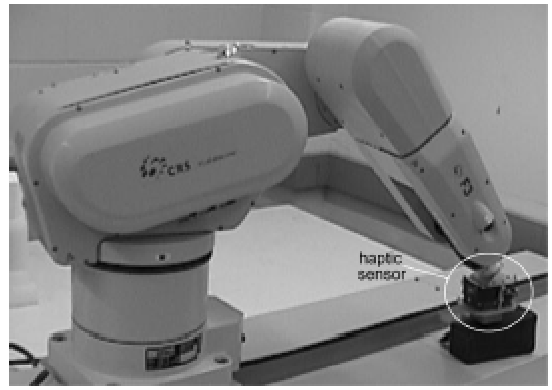
There are many of them! A few examples:

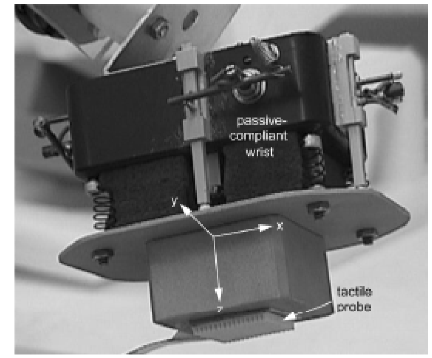
- Robotic Grippers/Manipulators
  - Fingertips of grippers or actuators
- Medical
  - Rehabilitation and service robotics
  - Minimally invasive surgery
- Consumer Electronics/Industrial
  - Touch screen phones

Many tactile sensors are customized, so, built by research institutions for different purposes.

Application: Robotic manipulation

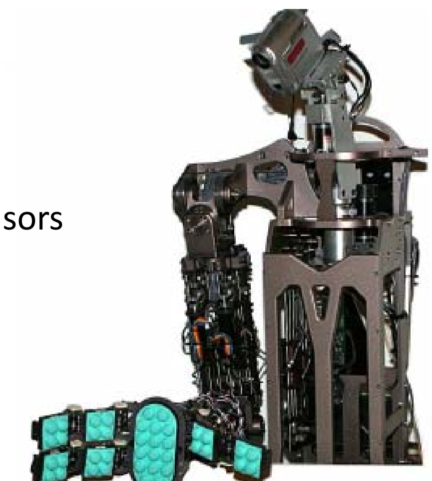
[Shadow Robot Company, England]

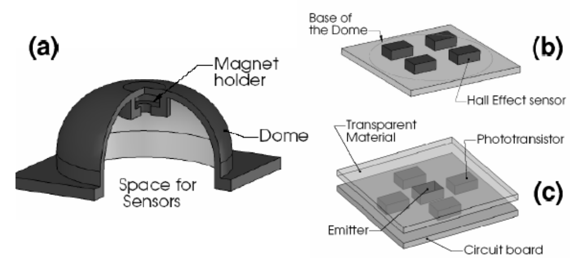




[Payeur, *et al.,* “Intelligent Haptic Sensor System for Robotic Manipulation”]

[Torres-Jara, *et al.,* “A soft touch: Compliant Tactile Sensors for Sensitive Manipulation”]





Application: Nasa’s Robonaut

- One of the examples directly related to planetary exploration.
- Nasa wants use this on the International Space Station, helping humans with repairing/maintenance tasks in cluttered environments.
- They tried many tactile sensors (initially Force-Sensitive-Resistors(FSR), now Quantum Tunneling Composites (QTC))

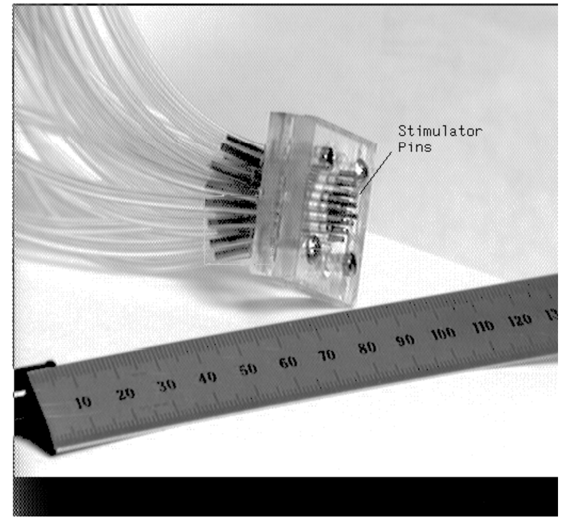
[Martin, *et al.,* “Tactile gloves for Autonomous Grasping with the NASA/DARPA Robonaut”]

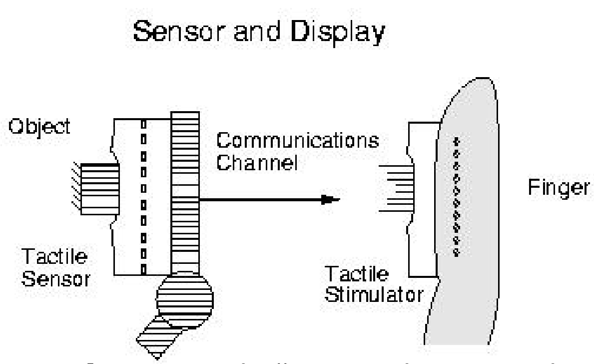
Figure 3. Conceptual Robonaut Centaur configuration

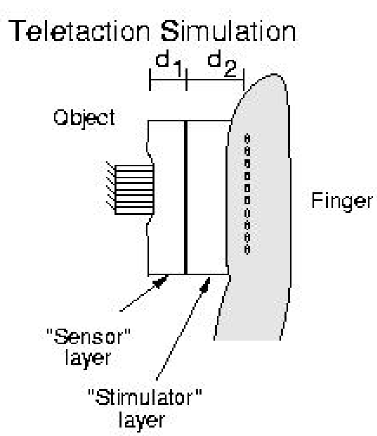
http://en.wikipedia.org/wiki/Quantum_Tunneling_Composite

Application: Tactile Displays

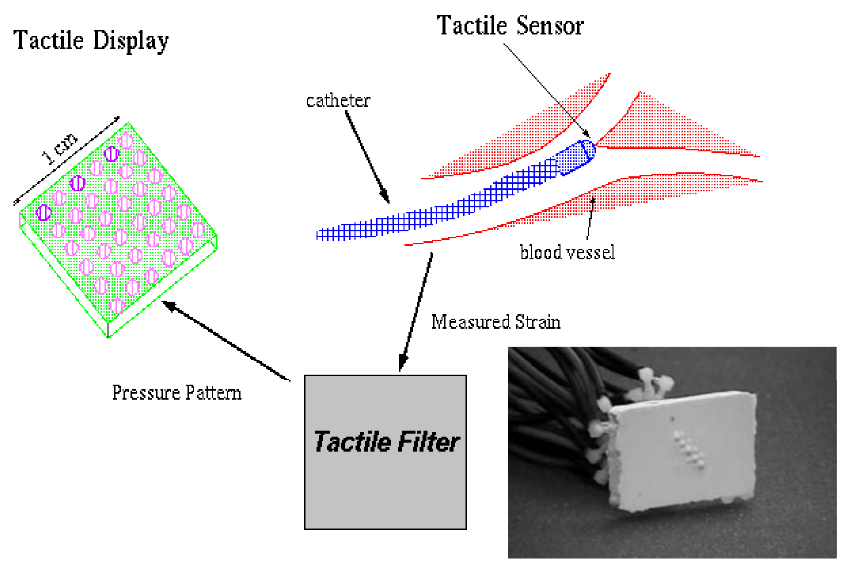
- The inverse problem:
  - When the collected data is to be presented directly to human as touch, force feedback…
- UC Berkeley’s tactile display: 5 x 5 array of pneumatic pins
  - 0.3 N per element, 3 dB point of 8 Hz, and 3 bits of force resolution







[Moy, *et al.*, “A Compliant Tactile Display for Teletaction, ”]



Human mechanoreception:

- Understanding human touch is important because in the case of displays, it is an upper limit, in the case of sensors, it is a reference point.
- "An ideal display requires 50 N/cm^2 peak pressure, 4 mm stroke, and 50 Hz bandwidth; that is, a power density of 10W/cm^2 with an actuator density of 1 per mm^2". [Moy, *et al.,* "Human Psychophysics for Teletaction System Design"]

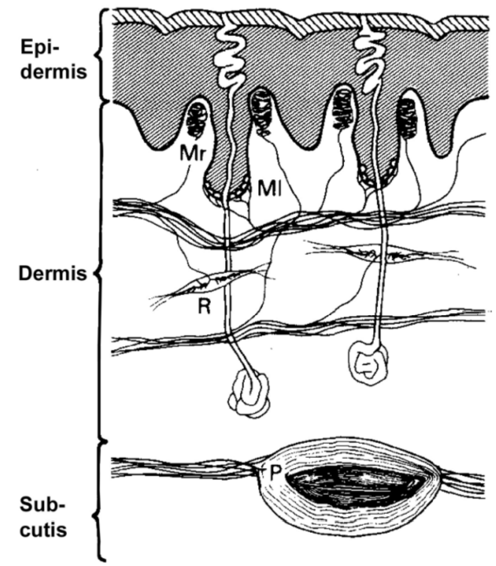
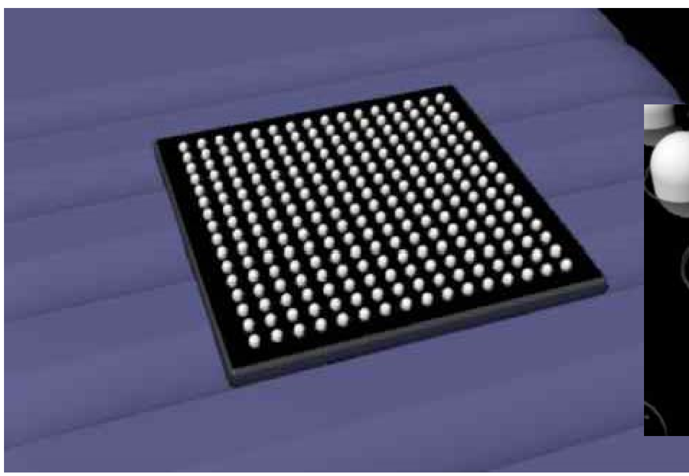


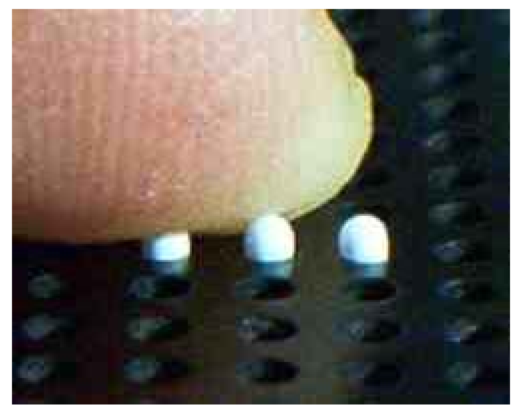
Table 2-1. Characteristics of mechanoreceptors found in human fingertip skin (sensed parameters suggested by Johnson and Phillips 1981, Johansson, Landstrom, and Lundstrom 1982 and Vallbo and Johansson 1984).

Receptor	Receptor Type	Field Diameter	Frequency Range	Sensed Parameter
Merkel Disks	SAI	3-4 mm	DC-30 Hz	Local skin curvature
Ruffini Endings	SAII	>10 mm	DC-15 Hz	Directional skin stretch
Meissner Corpuscles	FAI	3-4 mm	10-60 Hz	Skin stretch
Pacinian Corpuscles	FAII	>20 mm	50-1000 Hz	Unlocalized vibration

Application:
Tactile Displays for the blind

- Display with 256 tactile dots on an area of 4 x 4 cm
- Displays characters instead of Braille cells
- Piezoelectric actuators
- Can read from cell phone screen and show video (black-white)!

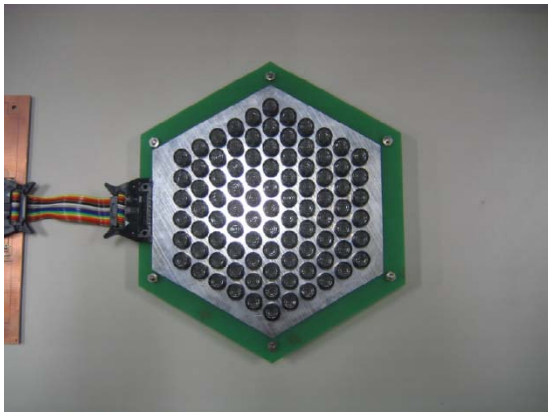




http://www.abtim.com/home__e_/home__e_.html

Application: Ultrasound tactile display

- It creates and focuses ultrasonic pressure using 91 transducers. (no air flow, localized pressure)
- 20 Pa at 300 mm, at 40kHz
- “Now we are developing a 3D interaction system which enables its users to handle 3D graphic objects with tactile feedbacks without any gloves or wearable devices.”
- I think it means “variable or multiple focal points”



[Iwamoto, *et al.,* "Non-Contact Method for Producing Tactile Sensation Using Airborne Ultrasound," Proc. EuroHaptics 2008, LNCS 5024, pp. 504-513, June, 2008.”]

http://www.youtube.com/watch?v=hSf2-jm0SsQ&eurl=http://www.alab.t.u-tokyo.ac.jp/~siggraph/08/Tactile/SIGGRAPH08-Tactile.html&feature=player_embedded

Application: Ultrasound tactile display

[Iwamoto, *et al.,* "Non-Contact Method for Producing Tactile Sensation Using Airborne Ultrasound," Proc. EuroHaptics 2008, LNCS 5024, pp. 504-513, June, 2008."]

http://www.youtube.com/watch?v=hSf2-jm0SsQ&eurl=http://www.alab.t.u-tokyo.ac.jp/~siggraph/08/Tactile/SIGGRAPH08-Tactile.html&feature=player_embedded

Application: A haptic system; Tele-nano-manipulation

- From NanoRobotics Lab at CMU.
- A combination of a sensor (AFM) and a robotic device for human interaction
- An atomic force microscope scans the specimen, and interfaces to the human as force feedback, using a robotic arm (Force Dimension Inc.)

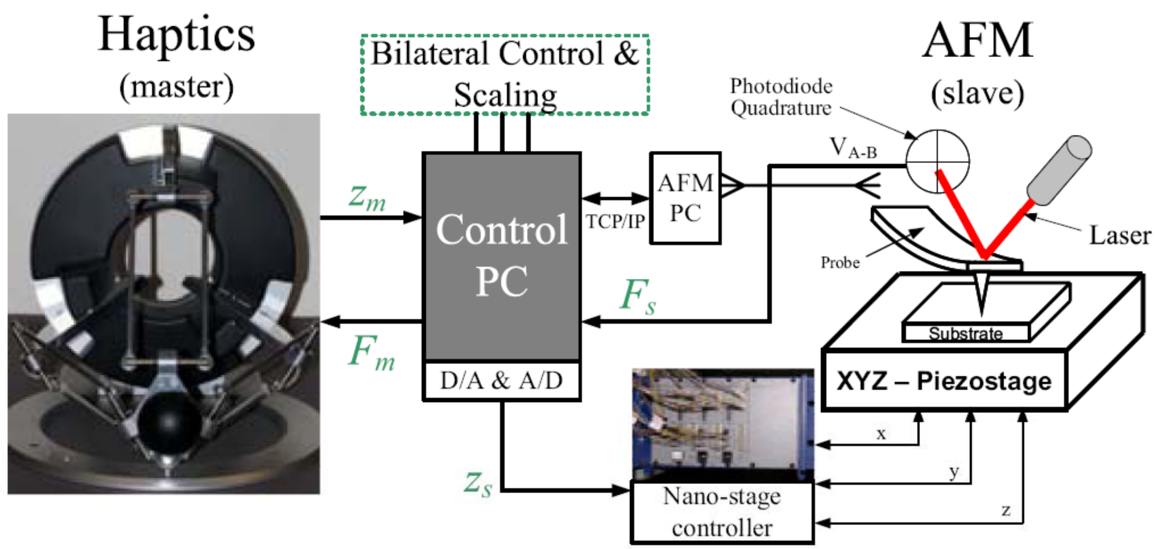
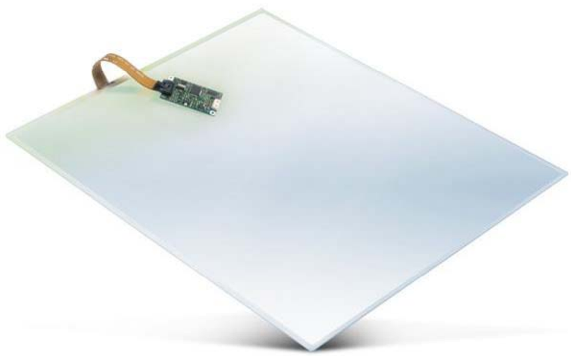


Fig. 1. System layout of the teleoperated nanomanipulation system using a haptic device on the master side and an AFM on the slave side.

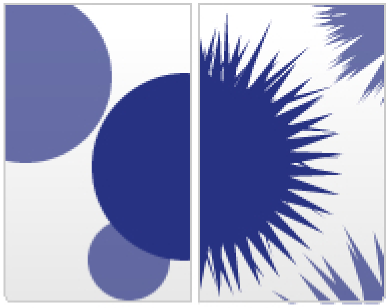
[Onal, *et al.*, "A Scaled Bilateral Control System for Experimental 1-D Teleoperated Nanomanipulation Applications," IEEE/RSJ Int. Conf. on Intelligent Robots and Systems, pp. 483-488, October 2007]

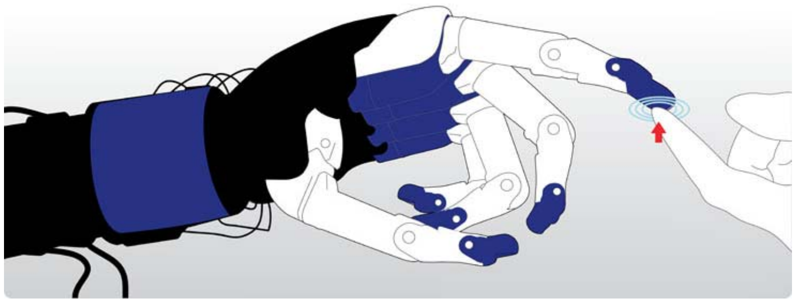
Some commercial tactile sensors you can buy today (1)

- Elo Touchsystems (Tyco Electronics):
  - Touch screens for kiosks, ATMs, etc…
  - Positional accuracy ≈ 5mm
  - Price ≈ 100$ - 300$ for (10” x 12”)
  - Capacitive, resistive, acoustic…
  - http://www.elotouch.com/Products/Touchscreens/default.asp



- Peratech, Ltd., in Durham, England
  - Quantum Tunneling Composite
  - Pressure switching and sensing material technology
  - Unstressed Resistance ≈ 10^{12}Ohms , Under Stress ≈ 1 Ohm
  - Flexible, durable, easily integrated sheets
  - More sensitive than Force-Sensitive-Resistor
  - (metal particles with spikes!)
  - http://www.peratech.com/index.php





Some commercial tactile sensors you can buy today (2)

- Tactex Array and multi touch interfaces
  - Optical tactile sensor – Fiber optic sensor pad
  - Photo transmitter receiver embedded in a foam
  - Rigid or Flexible
  - 100 to 600 sensing elements
  - Letter-size to mattresses for sleep monitoring
  - http://www.tactex.com/

- Interlink Electronics
  - Touchpads and Force-Sensitive-Resistors (FSR)
  - Price < 5$ for each FSR unit

Standard FSR Solutions
SKU: 400 FSR
Stock #: 30-49649
Price: $3.50
add to cart

The 400 FSR has a 0.16" (4 mm) diameter active area and is has solder tabs for the connection. **$75 Minimum Order.**

Standard FSR Solutions
SKU: 402 FSR
Stock #: 30-81794
Price: $4.00
add to cart

The 402 FSR has a 0.5" (12.7 mm) diameter active area and is has solder tabs for the connection. **$75 Minimum Order.**

- Shadow Robot Company

Directions for Future Research

- Flexible substrates for skin-like tactile sensors? Seems like there are many publications related to the fabrication of sensors on flexible (and conformal) substrates.
- Materials with different surface properties (durable, self cleaning)
- Different display mediums (acoustic)
- Slip Sensing (detecting how it initiates)

Researchers

- Chang Liu, University of Illinois, Urbana-Champagne.
  - Flexible tactile sensor skin

  (The author of a famous MEMS book)
- Ron Fearing, UC Berkeley
  - Tactile Sensor/Display for Teletaction
- S. Payandeh, Simon Fraser University, Burnaby, Canada
  - Tactile Sensor for an Endoscopic Grasper

Labs that work on tactile sensing and Haptics

- There are many groups in Japanese robotics industry and academia.
- MIT, Touch Lab, Artificial Intelligence Laboratory.
- The Haptics Laboratory at McGill University.
- Tactile Research Laboratory at The Naval Aerospace Medical Research Laboratory
- Haptics Laboratory, Johns Hopkins University

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