Touch – tactile perception for robots

Václav Hlaváč

Czech Technical University in Prague

Faculty of Electrical Engineering

Prague, Czech Republic

http://cmp.felk.cvut.cz/~hlavac

hlavac@fel.cvut.cz

Human sense of touch

Lateral motion
Texture

Pressure
Hardness/softness

Static contact
Temperature

Unsupported holding
Weight

Enclosure
Global shape, volume

Rim following
More precise shape

Related human vocabulary

- **Tactile**
  - Perceptible to the sense of touch.
  - *From French tactile,*
  - *From Latin tactilis ("that may be touched, tangible").*
- **Touch**
  - Make physical contact with.
  - *From e.g. French toucher.*
- **Haptic**
  - Of or relating to the sense of touch; tactile.
  - *From Ancient Greek ἁπτικός (haptikos, "able to come in contact with"), ἅπτω (haptō, "I touch").*
- **Haptics**
  - (medicine) The study of the sense of touch.
  - (computing) The study of user interfaces that use the sense of touch.

Source: Wiktionary

Somatosensory system

- The touch impression touch is formed from several modalities.
- Somatosensory system comprising the receptors and processing centers to perceive touch, temperature, proprioception (body position from stimuli inside the body), and nociception (pain).
- Kinesthesia is the sense that detects bodily position, weight, or movement of the muscles, tendons, and joints.
- Receptors cover the skin and epithelia, skeletal muscles, bones and joints, internal organs, and the cardiovascular system.

A greater picture – a somatosensory system

Kinesthesia

- Location
- Configuration
- Motion
- Force
- Compliance

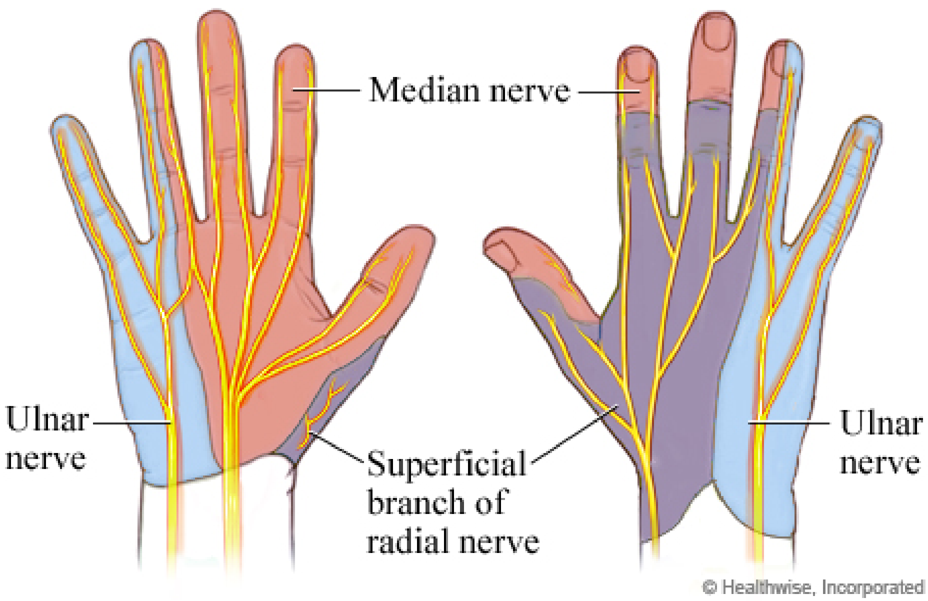
Cutaneous
(in the skin)

- Temperature
- Texture
- Slip
- Vibration
- Force

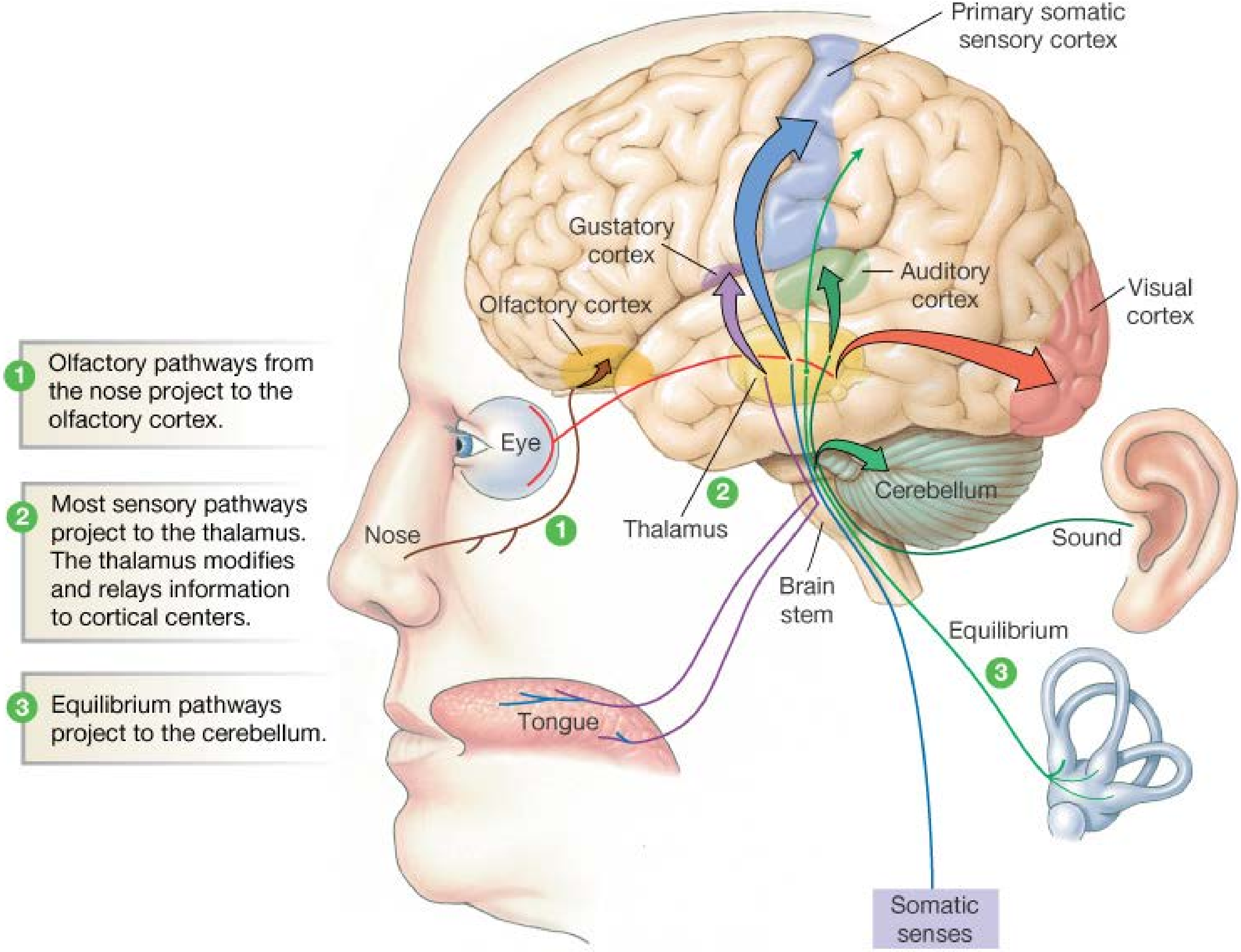
Human sensory physiology

Stimulus → Receptors → Afferent pathway → CNS integration

- Stimulus
  - Internal
  - External
  - Energy source
- Receptors
  - Sense organs
  - Transducers



External stimuli, special senses



Neurophysiological view

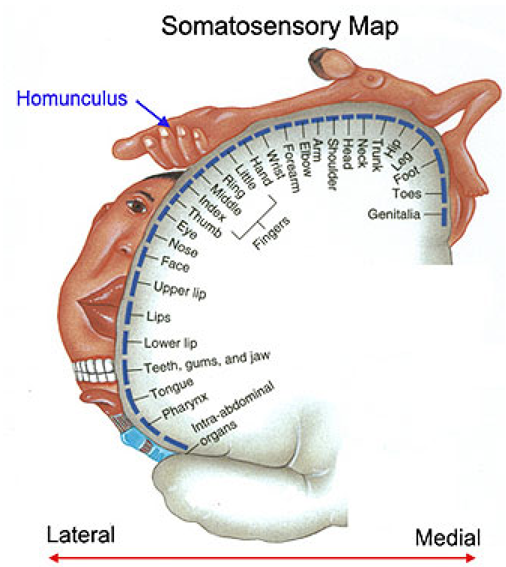
Somatosensory system

comprises of 3 parts:

- Exteroceptive cutaneous system.
- Proprioception system (monitors body position).
- Interoceptive system (monitors conditions within the body as blood pressure).

Cortical homunuculus

- Visualization of the point-to-point mapping between body surfaces (and function) to the brain surface.



Tactile sensing vs. haptics
in robotics and/or computing

Tactile sensing

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

Haptics

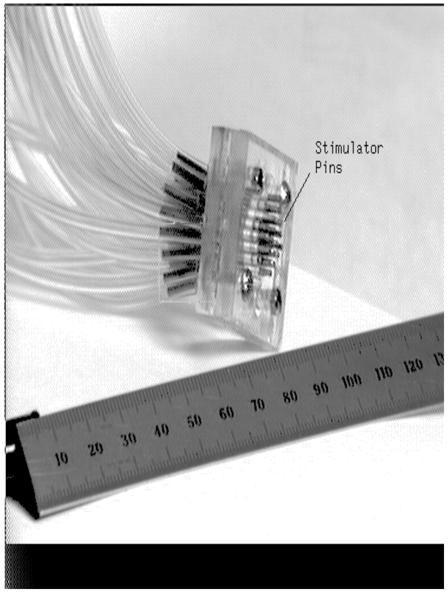
- Haptics explores human touch sense as a channel.
- The counterforce and its dynamics stimulates touch, compliance, vibrations, etc.
- ≈ 1 kHz loop needed.
- Two main devices:
  - Force feedback devices.
  - Haptic displays and rendering algorithms.

Haptics, ideas

- Haptics provides a human an additional communication channel to sight and sound in (computer) applications.
- The bidirectional communication is often secured by a keyboard and a mouse only.
- Haptics expands the bidirectional communi-cation by providing sensory feedback that simulates physical properties and force.
- Machine part of the haptic interface exerts forces to simulate contact with a virtual object.

Haptic devices

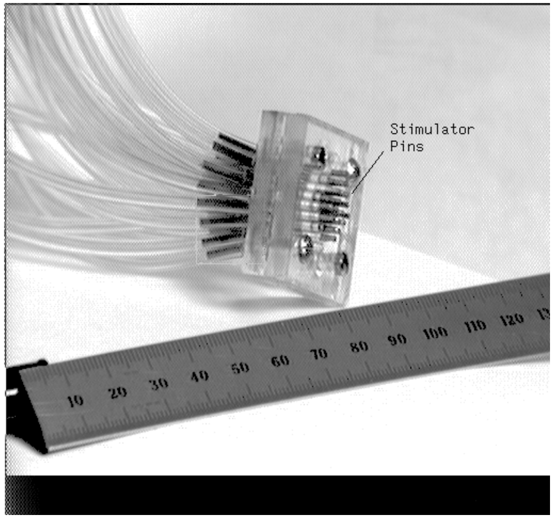
- Virtual reality / telerobotics:
  - Exoskeletons.
  - Gloves.
- Feedback devices:
  - Force feedback devices.
  - Tactile display devices.



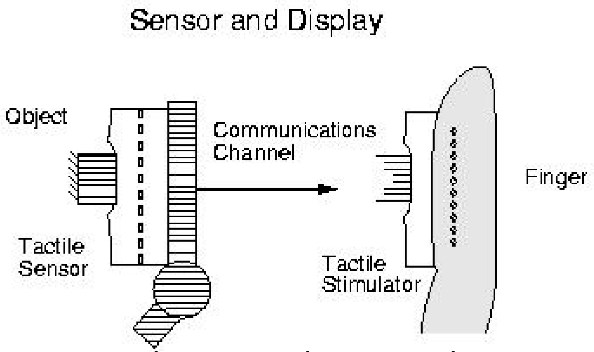
Haptics has many applications

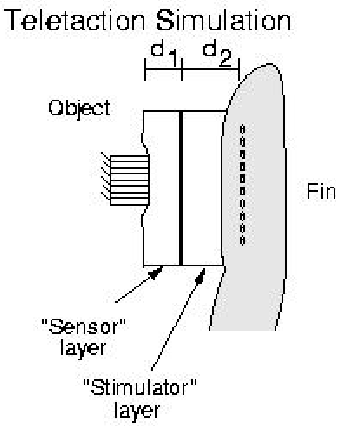
- Blind Persons
  - Programmable Braille
  - Access to GUIs
- Training
  - Medical Procedures
  - Astronauts
- Education
- Computer-Aided Design
  - Assembly-Disassembly
  - Human Factors
- Art
- Animation/Modeling
- Entertainment
  - Arcade (steering wheels)
  - Home (game controllers)
- Automotive
  - BMW “iDrive”
  - Haptic Touchscreens
- Mobile Phones
  - Immersion “Vibetonz”
- Material Handling
  - Virtual Surfaces

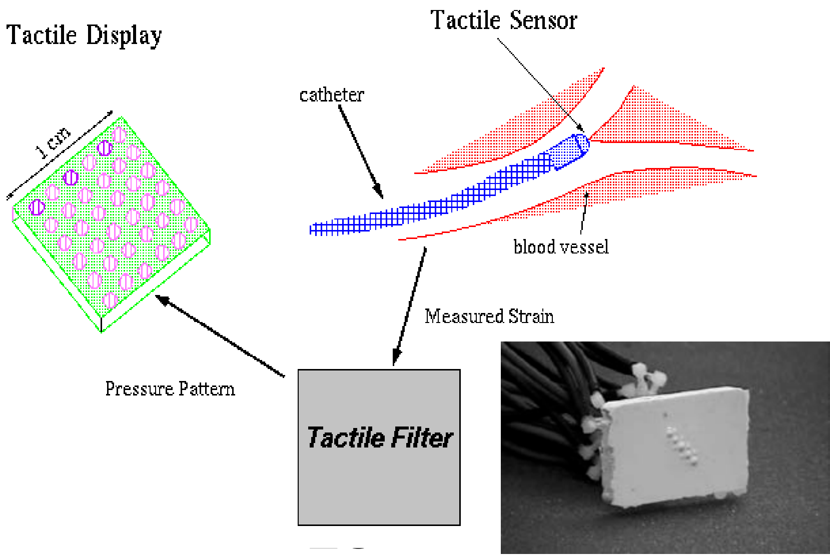
Pneumatic tactile display



- 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



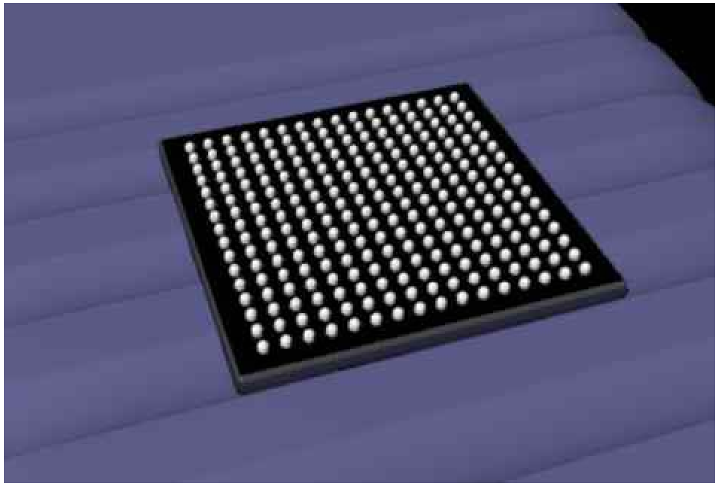


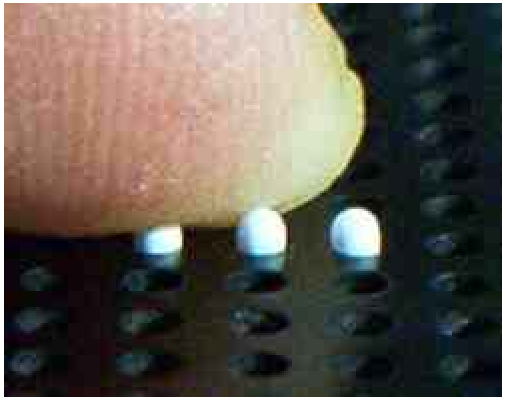


Moy, *et al.*, A Compliant Tactile Display for Teletaction, ICRA 2000

Piezoelectric display for blind

- Display with 256 tactile dots on an area of 4 x 4 cm.
- Displays characters instead of Braille cells.
- Piezoelectric actuators

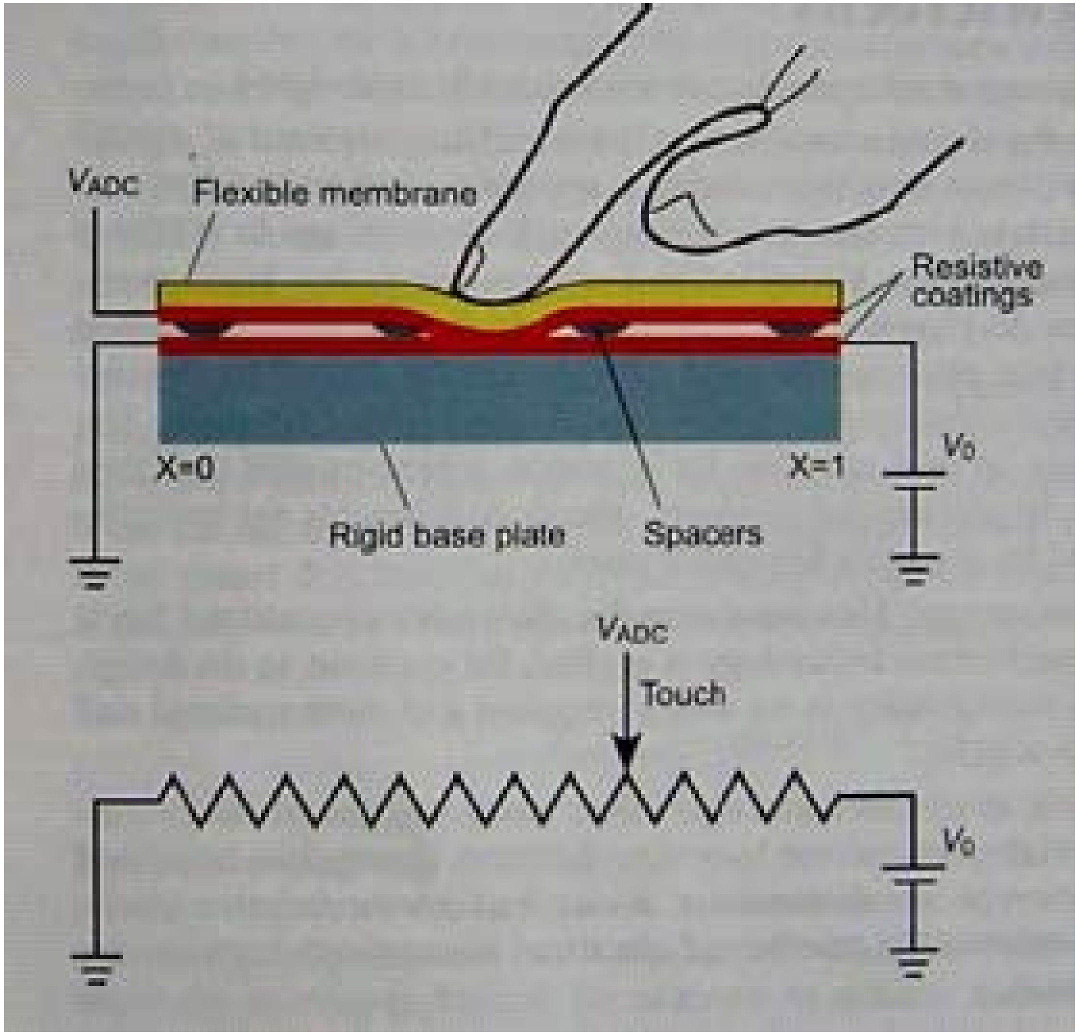




http://www.abtim.com/home__e_/home__e_.html

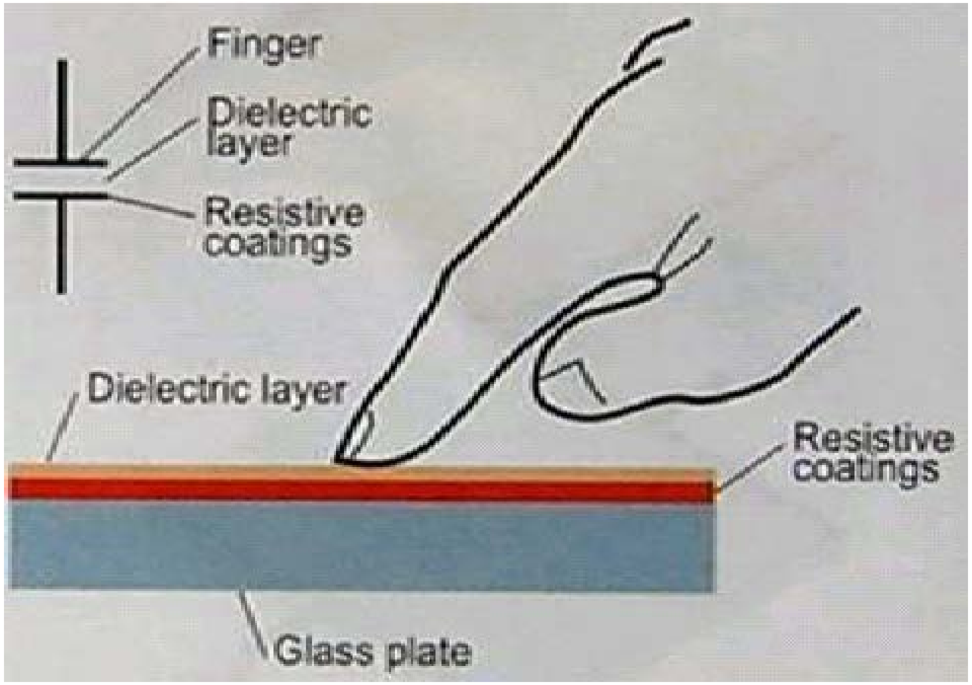
Resistive touchscreen

- Two flexible resistive layers are separated by a grid of spacers.
- When the two layers are pressed together the resistance can be measured between several points.
- This determines where the two resistive layers contacted.



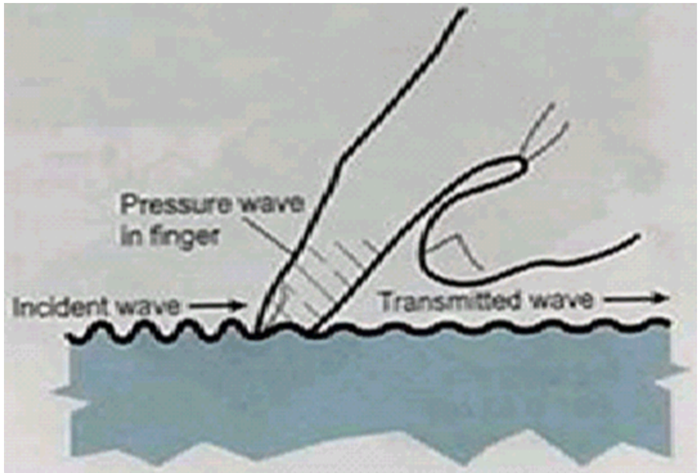
Capacitive touchscreen

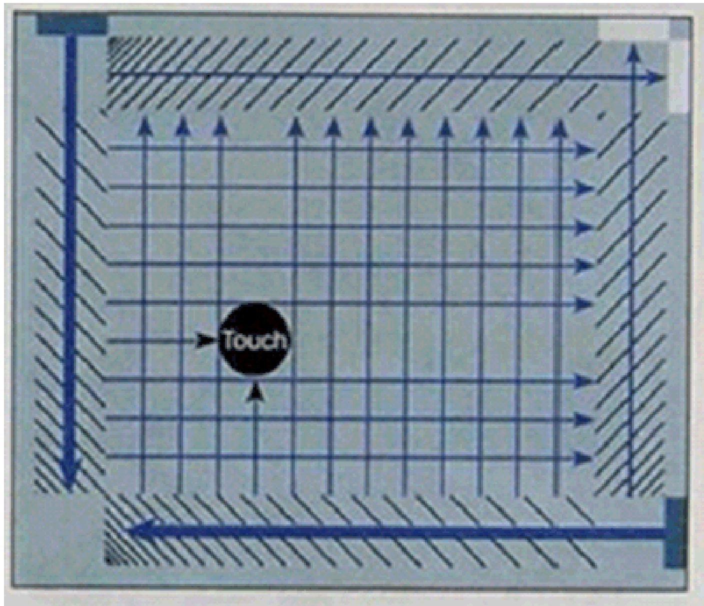
- A conductive layer is covered with a dielectric layer.
- The finger represents the other plate of the capacitor.
- A few kHz signal is transmitted through the conductive plate, the dielectric, and the finger to ground.
- The current from each corner is measured to determine the touch location.



Ultrasound touchscreen

- Ultrasonic sound waves (>40 kHz) are transmitted in both the horizontal and vertical directions.
- When a finger touches the screen, the waves are damped.
- Receivers on the other side detect where the sound was damped.
- Multiple touch locations are possible.



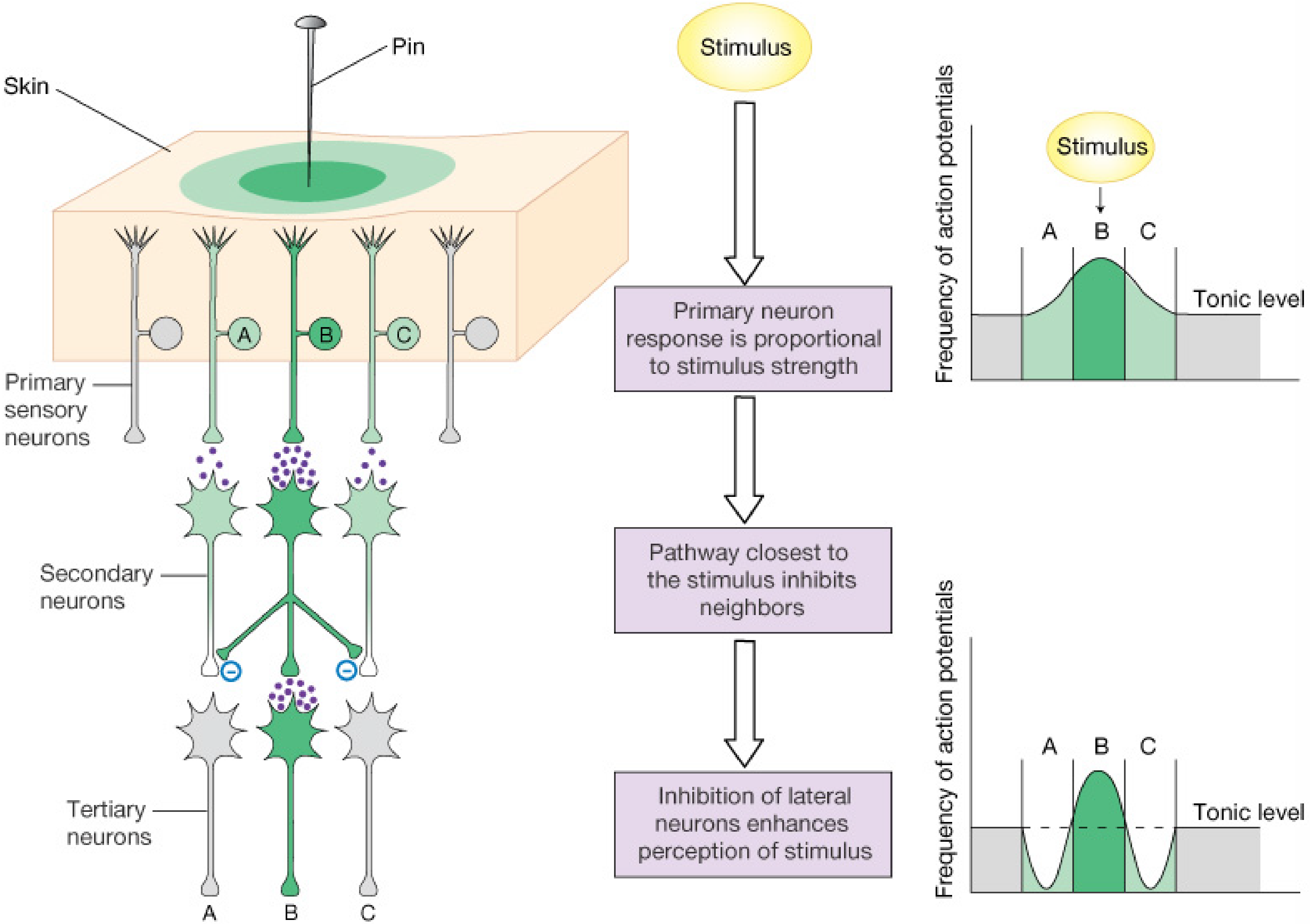


Glass plate with reflector arrays

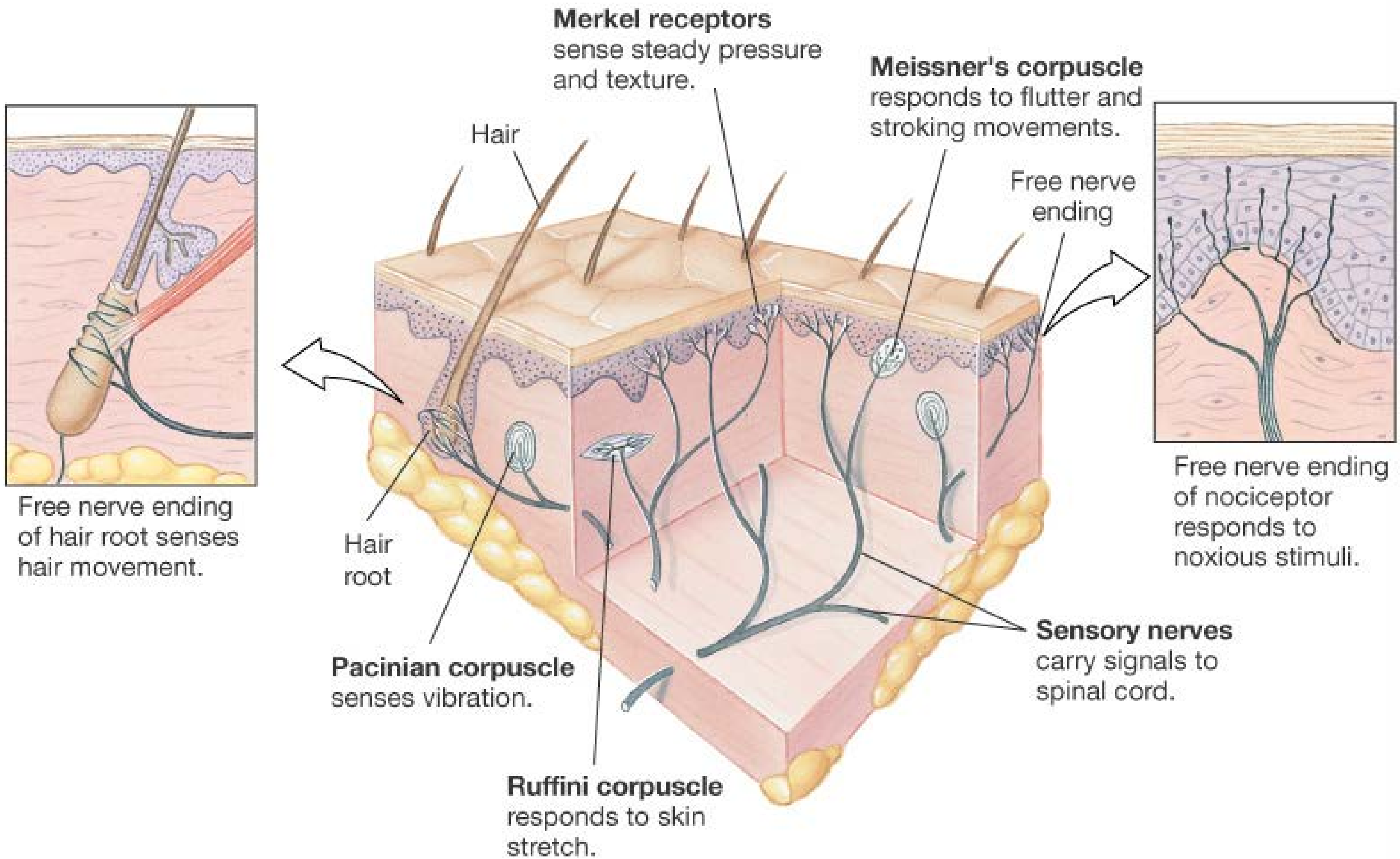
Touch reception in animals

- Touch reception (called also tangoreception) is a perception in an animal when in contact with a (solid) object.
- Two types of receptors are common:
  - Tactile hairs (in many animals from worms, birds to mammals). Some can be very specialized as, e.g., cat whiskers.
  - Subcutaneous receptors. Lie in “the skin”.

Sensory modality

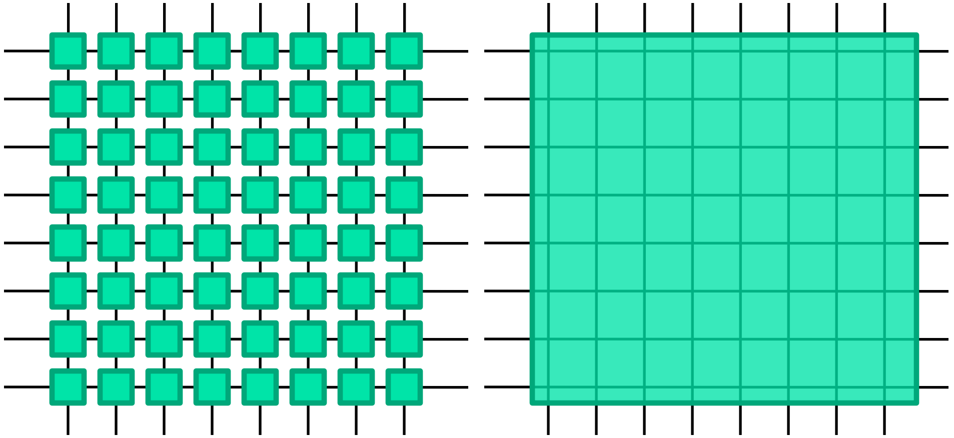


Various receptors in the skin



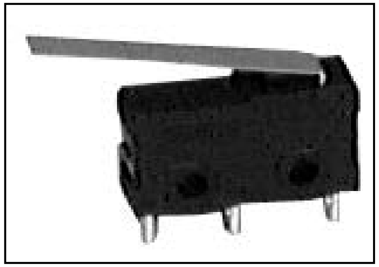
Principles of tactile sensors

- Mechanical – micro switch.
- Resistive – elastomer or foam.
- Capacitive.
- Magnetic (Hall effect).
- Piezoresistive.
- Etc

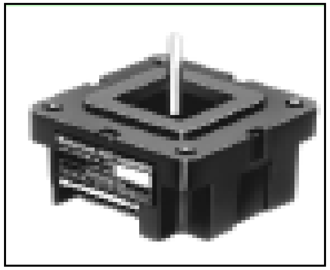


Mechanical sensor

- One Directional Reed Switch.



- Omni-Directional Reed Switch.



- Roller Contact Switch:

- Etc.

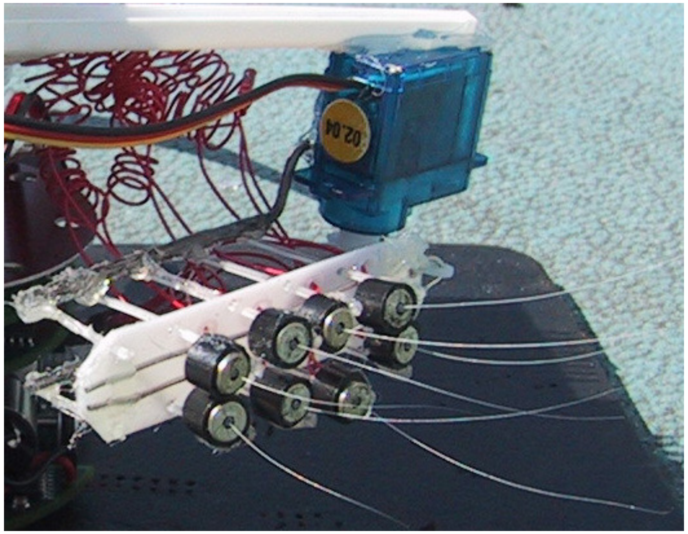
Whiskers

In nature:

- comparable to finger tips
- motion detection of distant objects
- navigation in the dark
- rich shape and texture information
- neural processing:
- model system for somatosensory processing

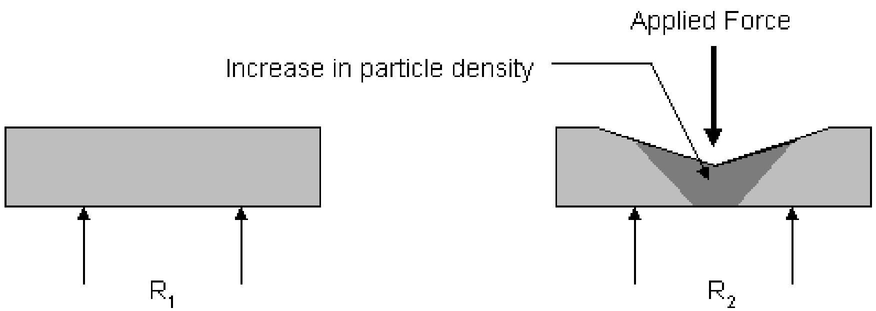
In robotics, so far:

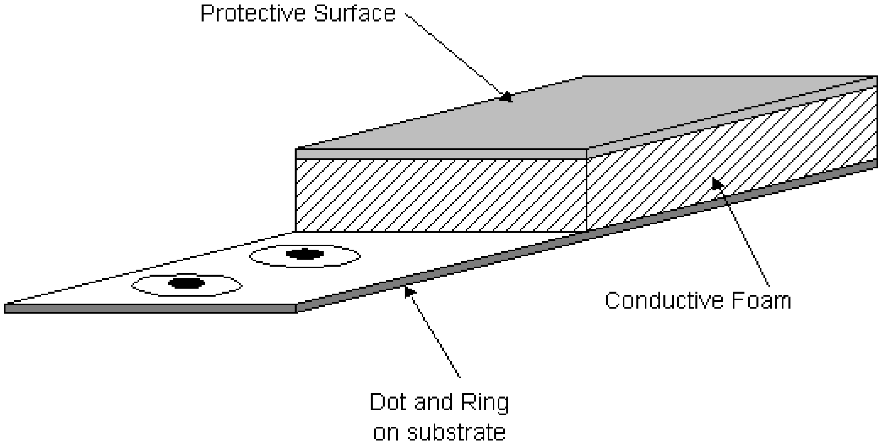
- limited (binary, strain sensors,
  bending angles)



Resistive sensor

- The basic principle is the measurement of the resistance of a conductive elastomer or foam between two points.
- The majority of the sensors use an elastomer that consists of a carbon doped rubber.

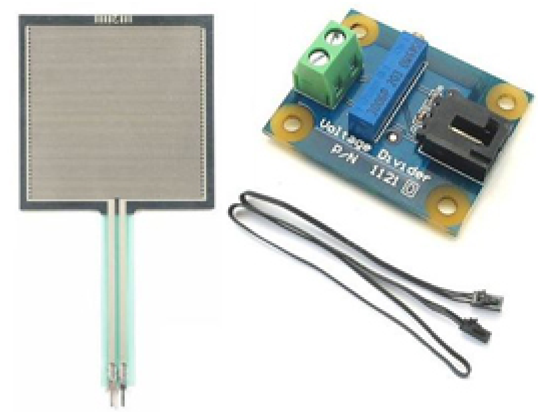


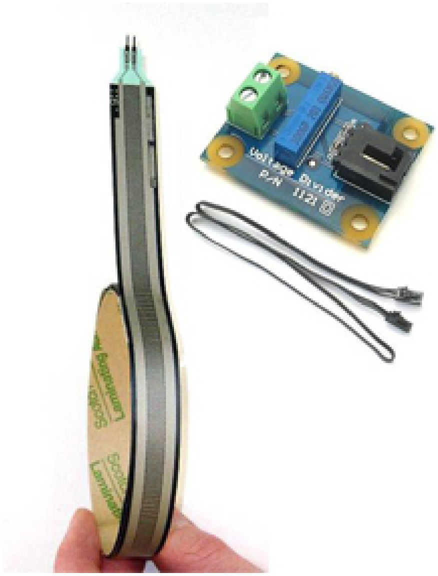


Disadvantages, resistive sensors

- An elastomer has a long nonlinear time constant, different for applying and releasing force.
- Highly nonlinear transfer function.
- Cyclic application of forces causes resistive medium migration within the elastomer in time.
- If the elastomer becomes permanently deformed then a fatigue leading to sensor malfuction.
- This will give the sensor a poor long-term stability and will require its replacement after an extended period of use.

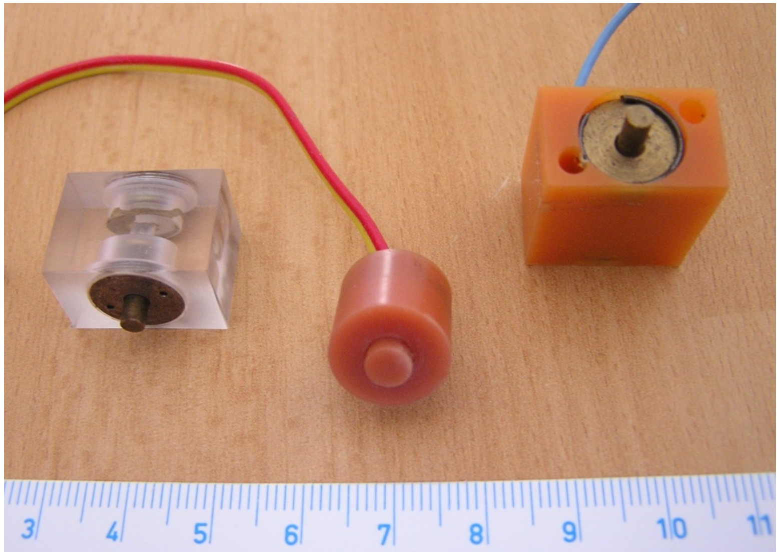
Common package and pricing

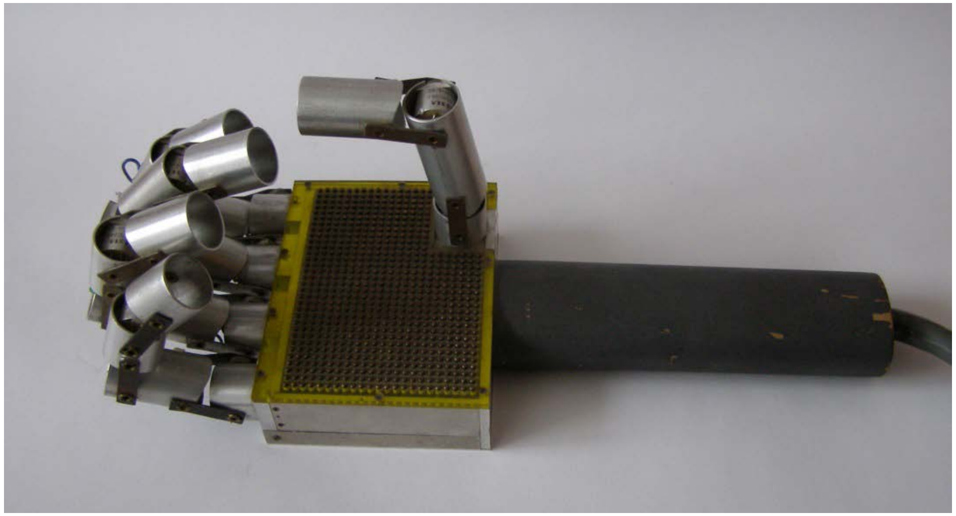




Price ranges from a few dollars to a few tens of dollars.

Resistive sensors, Jaromír Volf

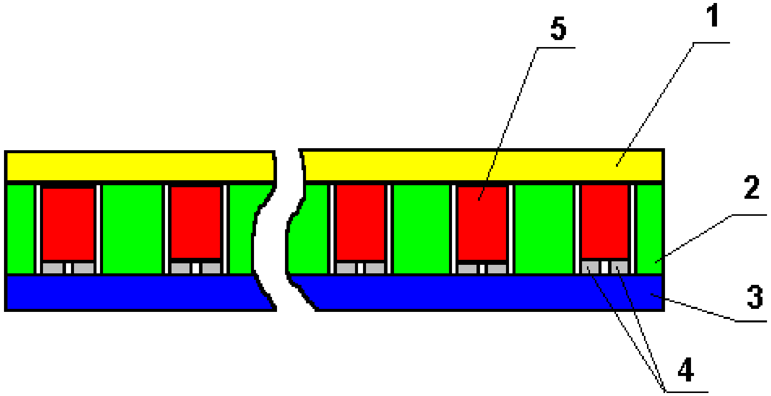




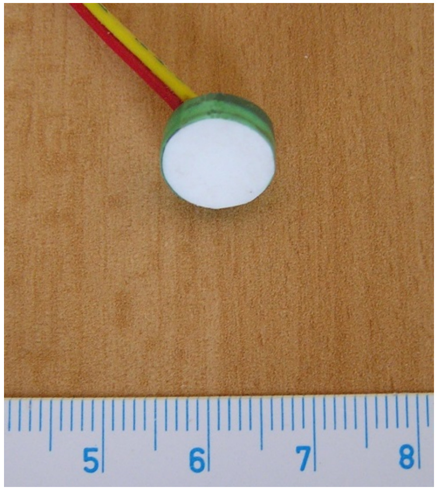
≈ 1981

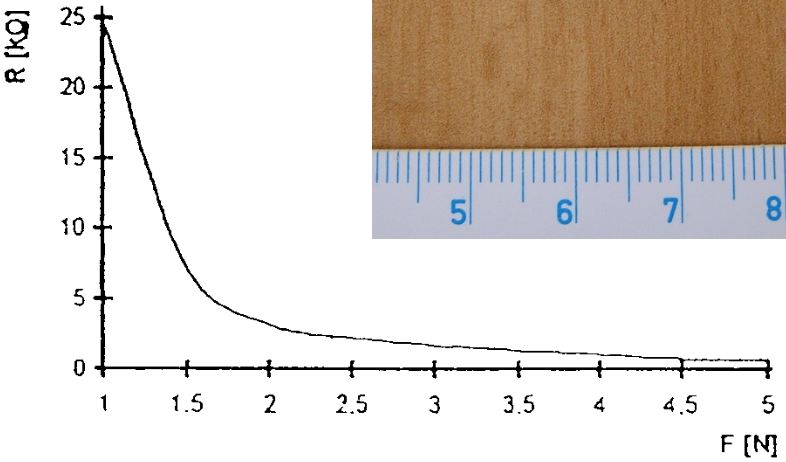
Resistive sensor PTM 1.3

- Jaromír Volf, Faculty of Mechanical Engineering CTU in Prague.
- Layout
  1. Cover layer.
  2. Distance insert.
  3. Base plate.
  4. Electrodes.
  5. Conductive elastomer.



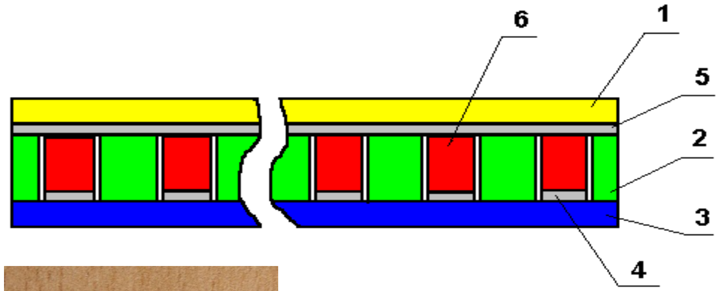
Tactile sensor PTM 1.3

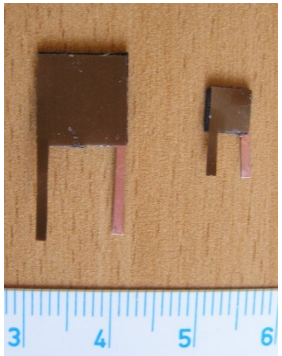


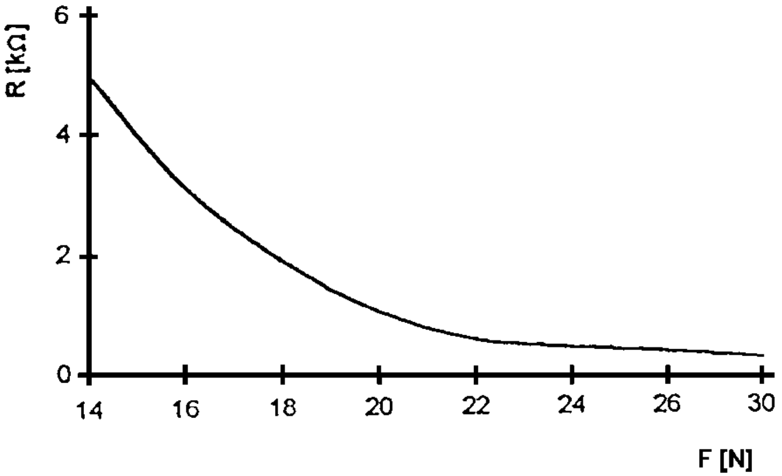


Tactile sensor PTM 1.4

- Jaromír Volf, Faculty of Mechanical Engineering CTU in Prague.
- Layout
  1. Cover layer.
  2. Distance insert.
  3. Base plate.
  4. Electrodes.
  5. Electrode.
  6. Conductive elastomer.





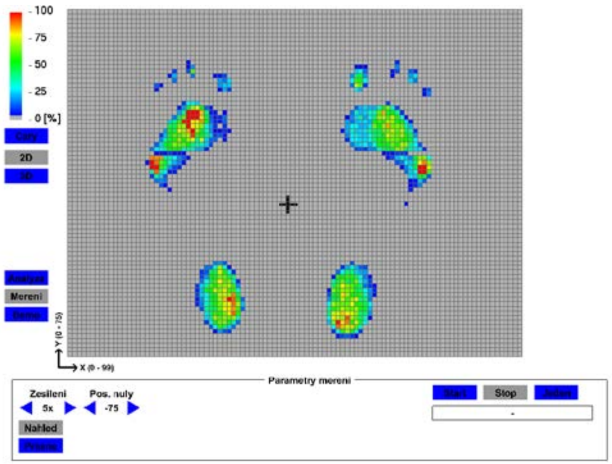


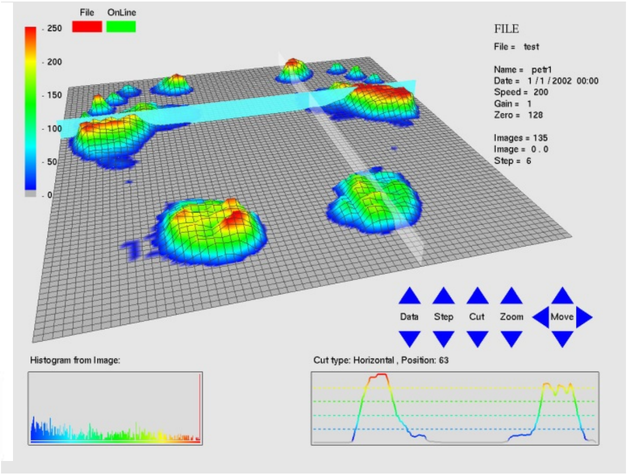
Plantograph V05, J. Volf

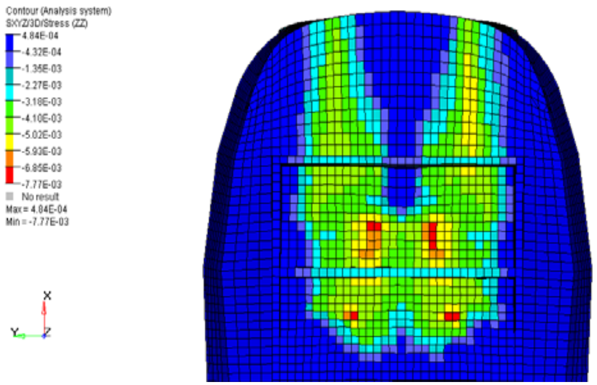
Specifications

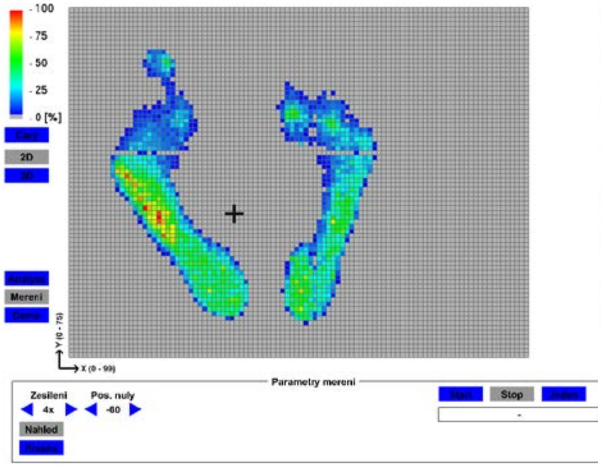
Active area of the sensor	300 x 400 mm
Number of sensors	7 500
Resolution	4 x 4 mm
Area of the singe sensor	2 x 2 mm
Measured pressure range	0 - 414 kPa
Allowed permanent overloading	1.4 MPa
Impact overloading	10 MPa
Frame frequency	300 Hz
Line frequency	25 kHz
Sampling frequency	300 kHz
Digital output range	256 pressure levels (8 bits)

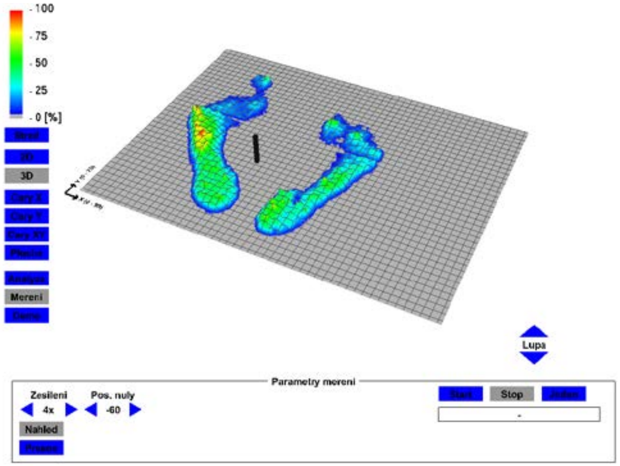
Plantograph, results

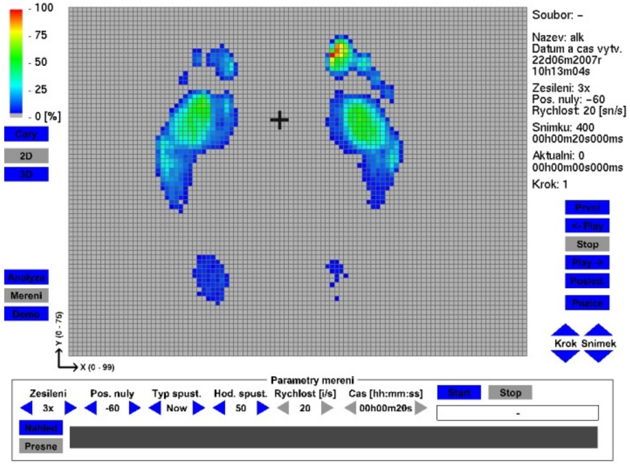




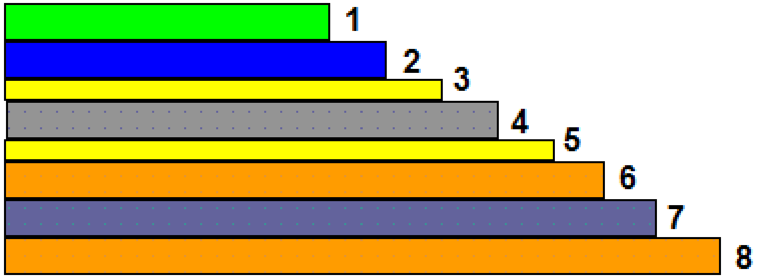


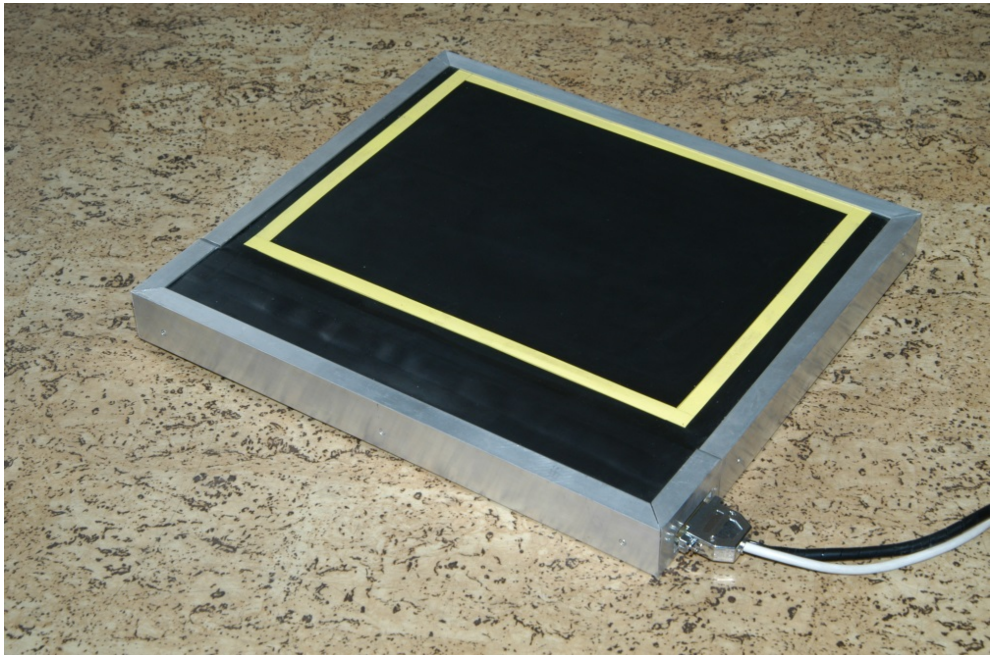






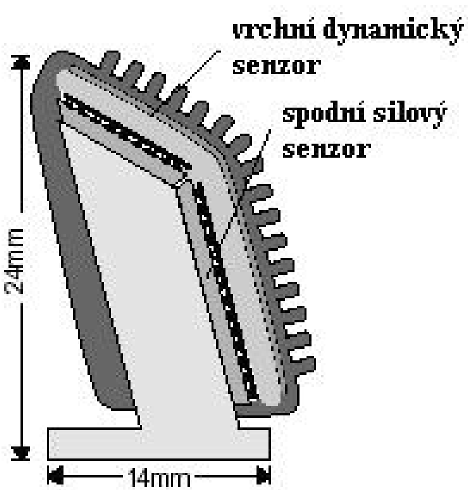
Plantograph construction

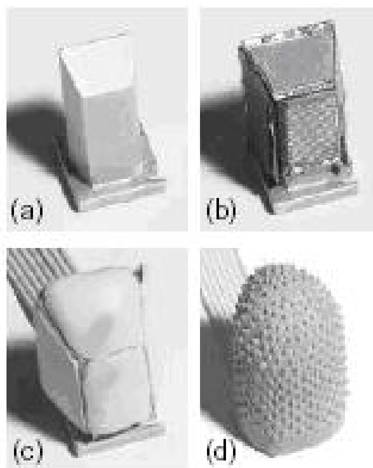


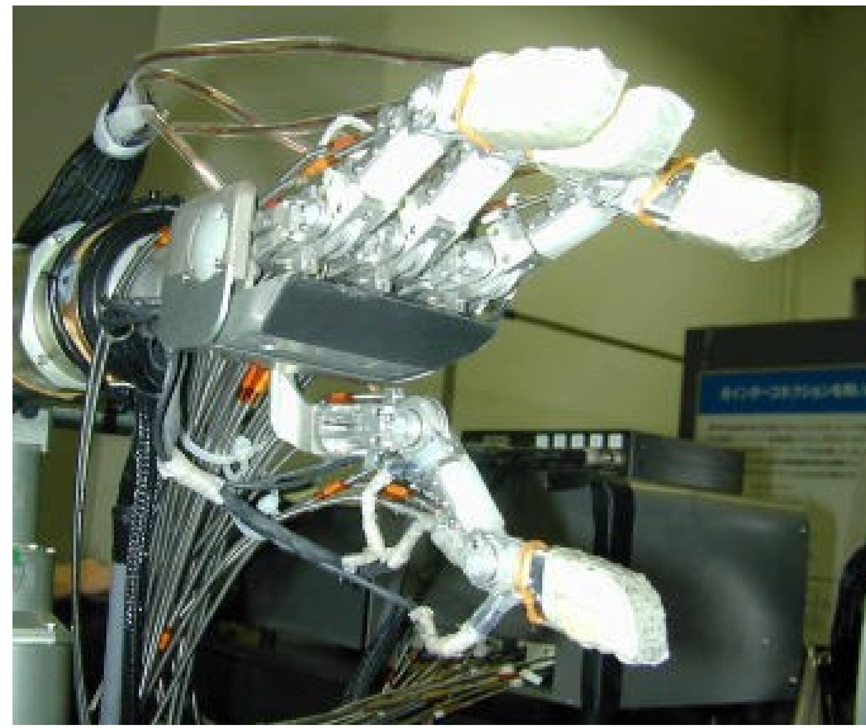


1 – cover layer
2 – shear force layer
3 – top electrode CUFLEX
4 – conductive elastomer CS 57-7 RSC
5 – bottom electrode CUFLEX
6 – antistatic layer
7 – duralumin plate
8 – antistatic layer

Two layers sensor

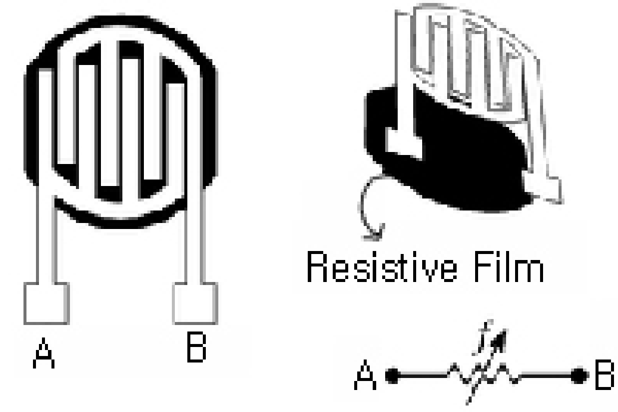


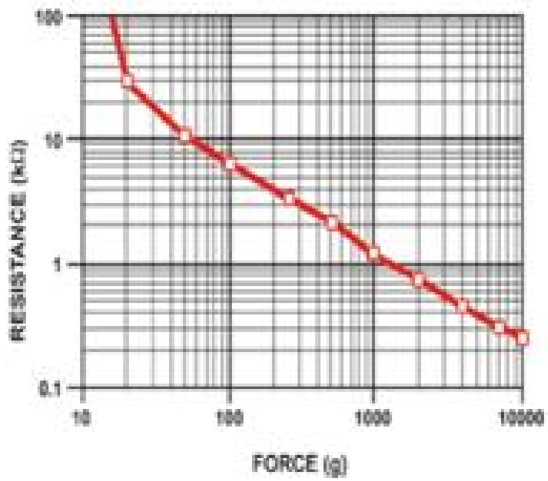


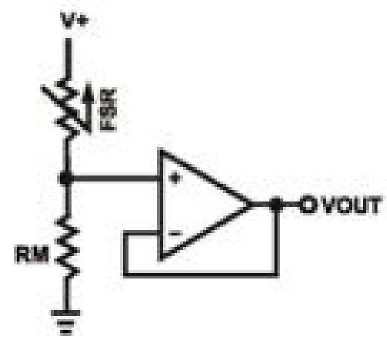


FSR sensor

- FSR = Force-Sensitive-Resistor
- Used also for touch keyboards.

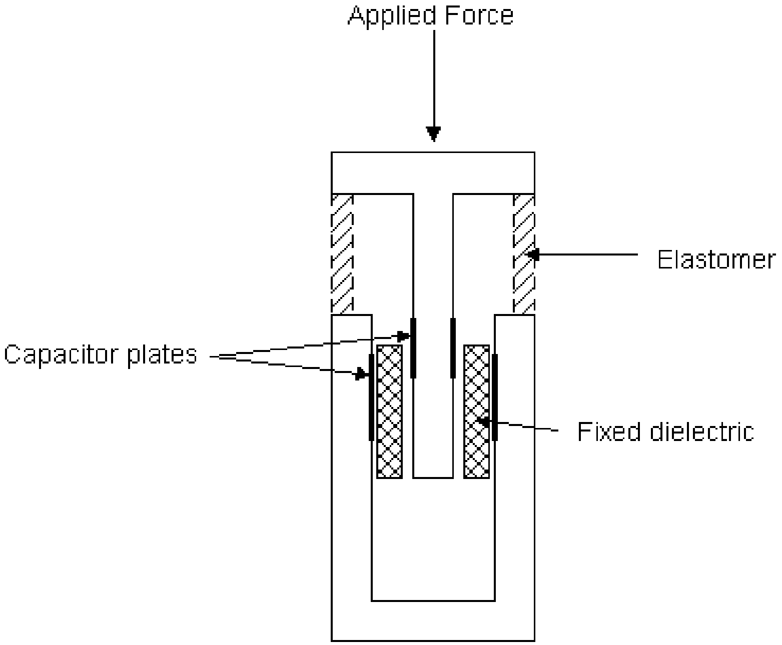






Capacitive sensor

- Capacitance between two parallel plates $C = \frac{\varepsilon A}{d}$, where ε is the permittivity of the dielectric medium A is the plate area, d is the distance between plates.
- The elastomer gives force-to-capacitance characteristic.

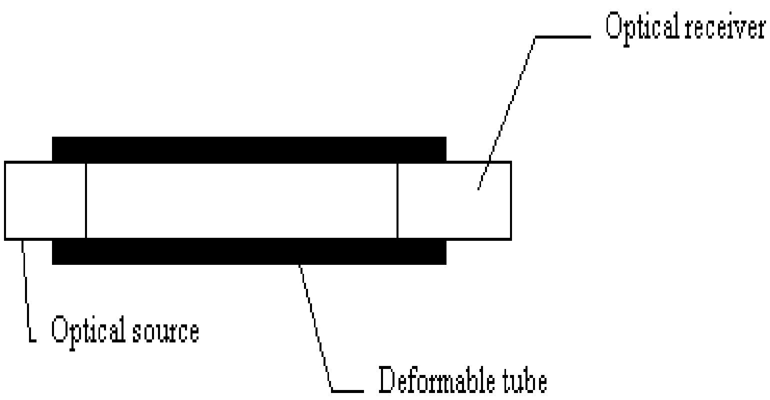


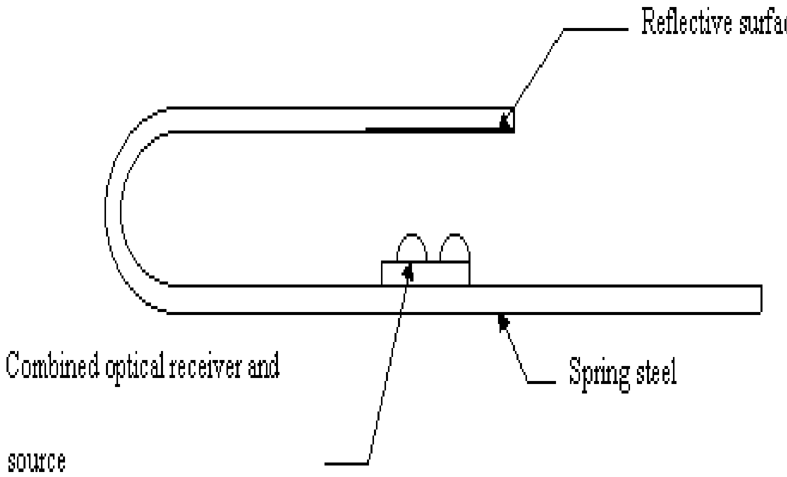
Capacitive sensor (2)

- As the size is reduced to increase the spatial resolution, the sensor's absolute capacitance will decrease.
- To maximize the change in capacitance as force is applied, it is preferable to use a high permittivity, dielectric in a coaxial capacitor design.
- The use of a highly dielectric polymer such as poly vinylidene fluoride maximizes the change capacitance.

Optical sensor

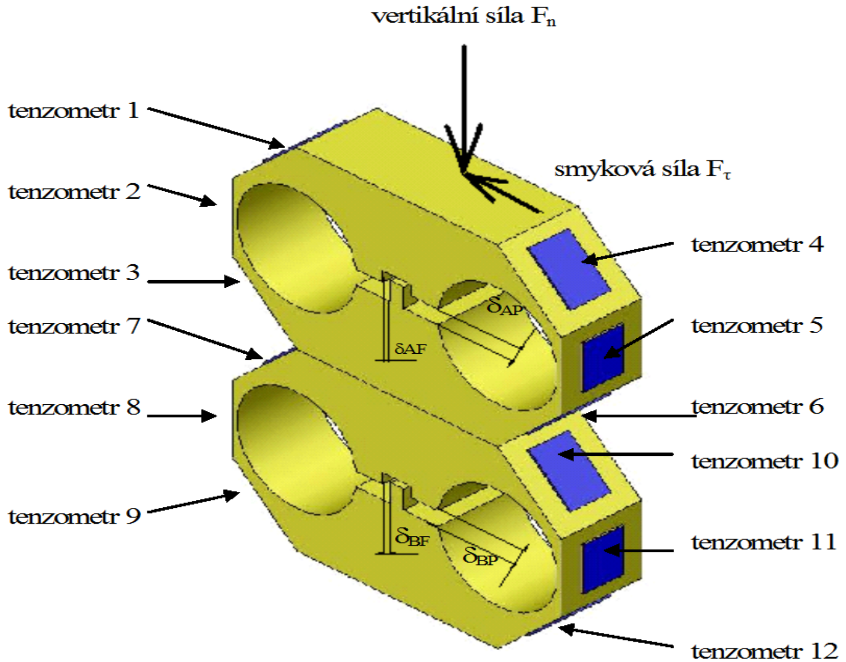
- The transmission or reflection is damped by the deformation due to applied force, which obstructs the light pathe.
- Top: deformable tube from elastomer.
- Botom: U shaped steel spring.

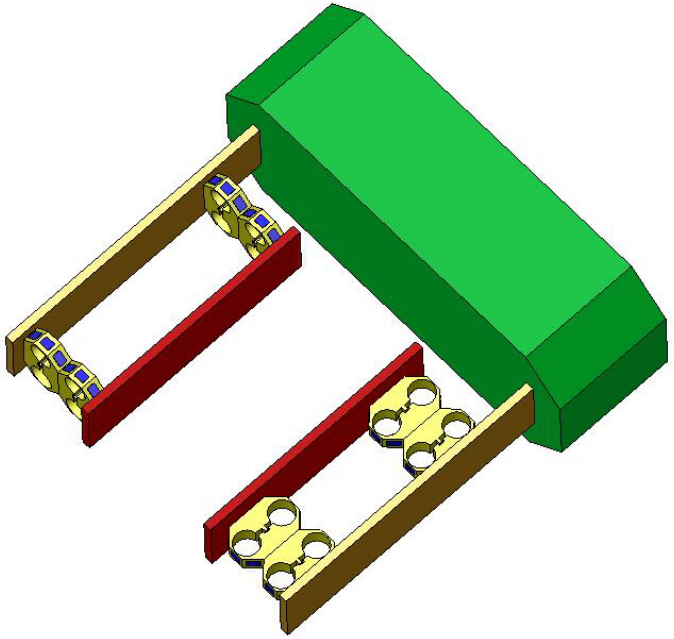




Tensometric sensor

- Measures also the shear force F_τ.
- Double Octagon Tactile Sensor (DOTS)

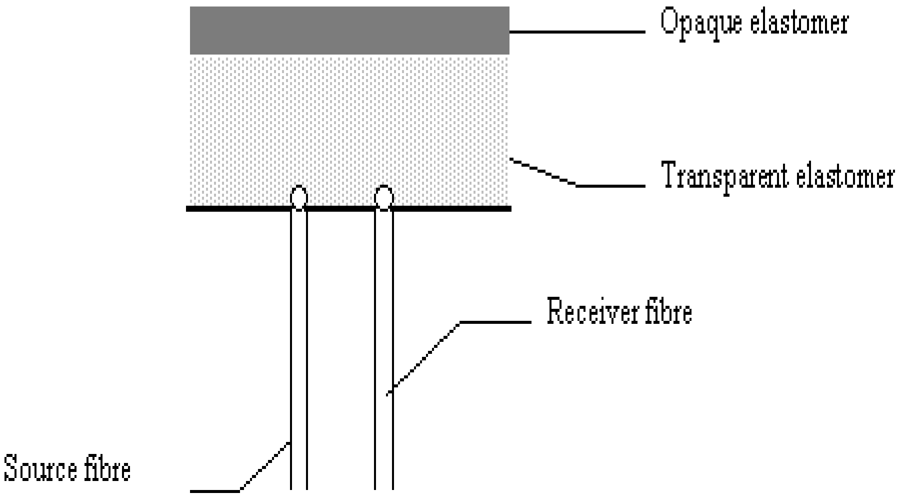




Application in a gripper

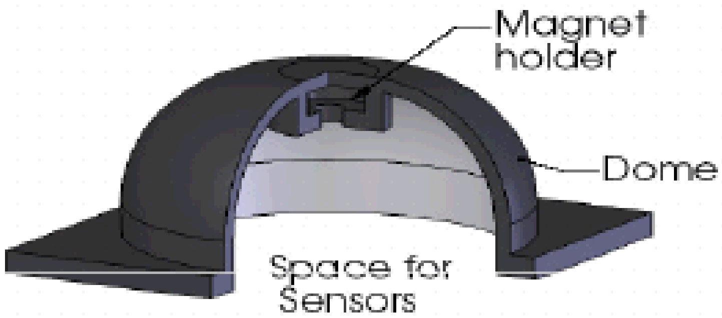
Optical sensor (2)

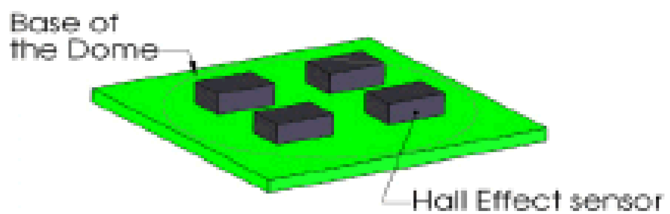
- A reflective sensors can be constructed with source-receiver fiber pairs embedded in an solid elastomer structure.
- The amount of light reflected to the receiver is determined by applied force, that changes the thickness of the clear elastomer.

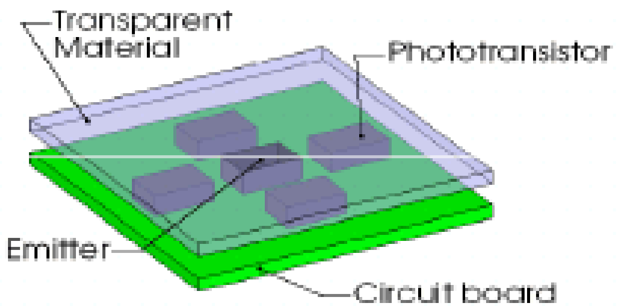


Skin sensor, magnetic or optical

- Position of the top of the sensor gives an estimation of the force applied.
- Magnetic version: magnet on the dome, 4 Hall effect sensors on the base.
- Optical version: A LED and 4 photo receptors on the base.

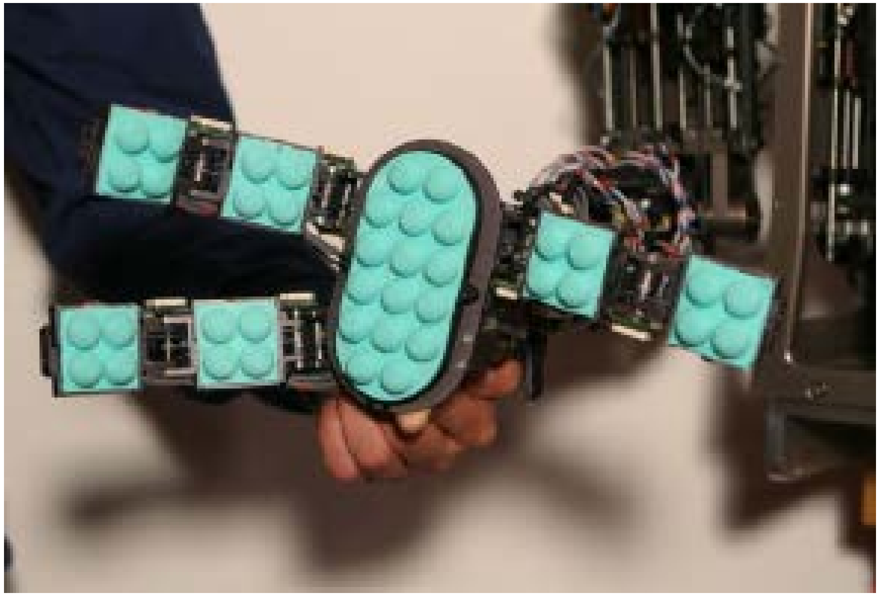






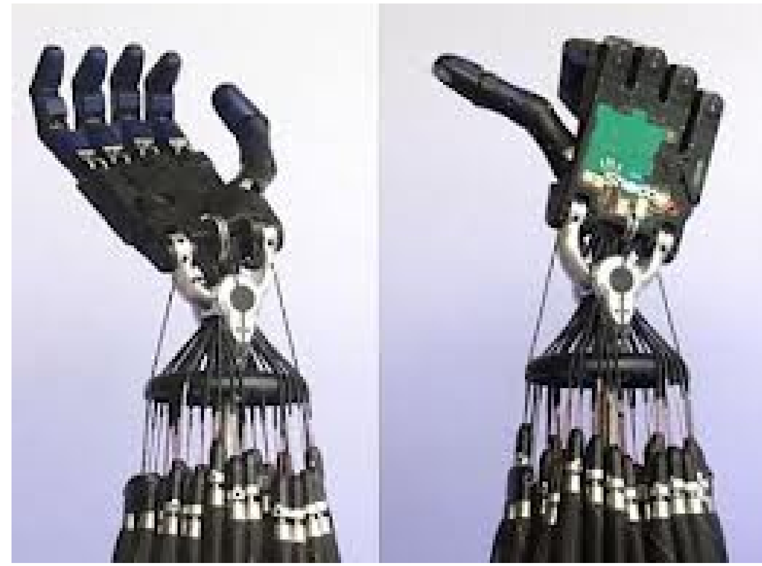
Skin sensor in the gripper

- 6 tactile sensors on the fingers and thumb.
- A tactile sensor has 4 domes with 4 hall effect sensors in each dome.
- Palm: 16 domes, each with 4 hall effect sensors.



Shadow hand, a top level model

- Shadow Dexterous Hand
- Shadow Robot Company, London, http://www.shadowrobot.com
- Actuation:
  - Pressurized air muscle
  - or Electric motor driven
- Hall effect sensors from Syntouch LLC
- ROS compatible
- Price ≈ USD 100k



Where to buy?

Tekscan http://www.tekscan.com/

PPS Pressure Profile Systems Inc. http://www.pressureprofile.com

TACTEX CONTROLS INC. Canadian, touch sensitive skins, bankrupt in 2007

XSENSOR Technology Corporation — Innovators in Pressure Imaging http://www.xsensor.com/

SOLARBOTICS LTD. https://solarbotics.com/

TakkTile http://www.takktile.com/

SPI SENSOR PRODUCTS INC. TACTILE PRESSURE EXPERTS http://www.sensorprod.com/

syntouch http://www.syntouchllc.com/

Conclusions

- Tactile sensing in robotics have not left research labs yet.
- Tactile sensing reliability and industrial proliferation is much smaller as compared to, e.g. robot vision.
- There are prospective teams, ideas, materials, companies (see previous slide), ongoing research projects, which might change the picture soon.