Tactile feedback technology & applications

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Based on material by Jukka Raisamo and Roope Raisamo

Methods for tactile stimulation

- The tactile sense can be stimulated using a variety of different methods

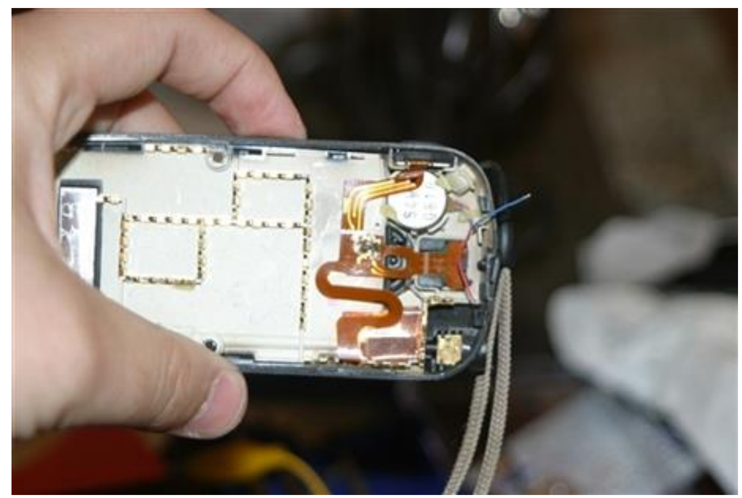
- These methods include:
  - Skin deformation
  - Vibration
  - Electric stimulation
  - Skin stretch
  - Friction (micro skin-stretch)
  - Temperature

Tactile actuators

- There are several different technologies used in tactile interfaces
  - Vibrating motors
  - Linear motors
  - Solenoids
  - Piezoelectric actuators
  - Pneumatic systems
  - ... *whatever causes an effect can be used*

- Possible actuator configurations
  - Single element
  - Multiple elements (an array/matrix)

Actuators: vibrating motors



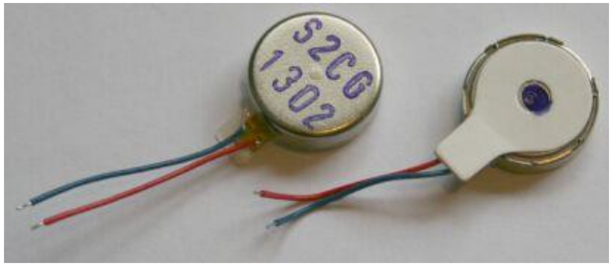
Vibrating motors

- How they work:
  - Applies motion either directly to the skin or through mediating structure
  - Provide relatively small-amplitude vibration (linear or rotary)
  - Used singly or in arrays

- Most common types
  - DC-motors with an eccentric rotating mass
  - Voice coils

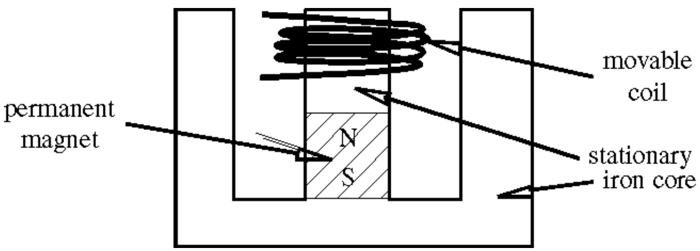
Vibrating motors: eccentric rotating mass

- DC-motor rotates an off-center spinning mass
  - Inexpensive & existing technology
  - Poor temporal resolution: it takes time to start and stop the mass
- Frequency control only (amplitude ~= $freq^2$)
  - Amplitude fixed by the size & the weight of the rotating mass and the speed of rotation
- Used currently in various devices
  - Mobile phones, pagers, game controllers



Vibrating motors: voice coils

- Voice coil basics
  - Current driven through the movable coil
  - Created magnetic field interacts with the field of the permanent magnet (one-way movement)
  - Vibrations created by switching the current on/off



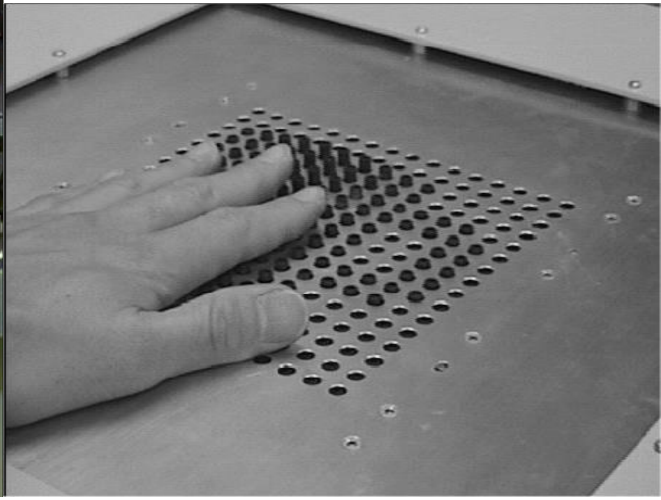
- Both frequency and amplitude can be controlled somewhat independently
  - However, the motor has always a peak at certain frequencies (e.g., 250 Hz)

Vibrating motors: overview

- Advantages:
  - Simple, existing technology
  - Relatively inexpensive
  - Easily powered and controlled
  - Quite small power consumption

- Disadvantages:
  - Not very expressive feedback
  - Vibration can sometimes be irritating
  - Can be hard to miniaturize efficiently

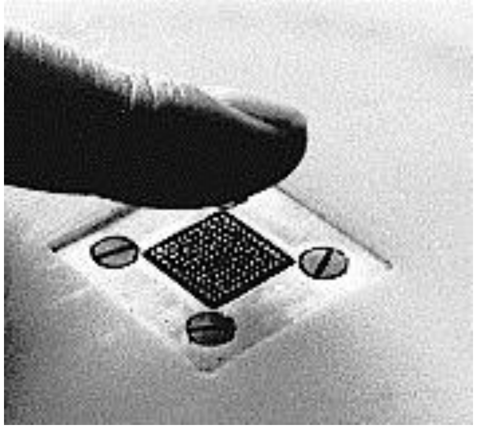
Actuators: linear motors

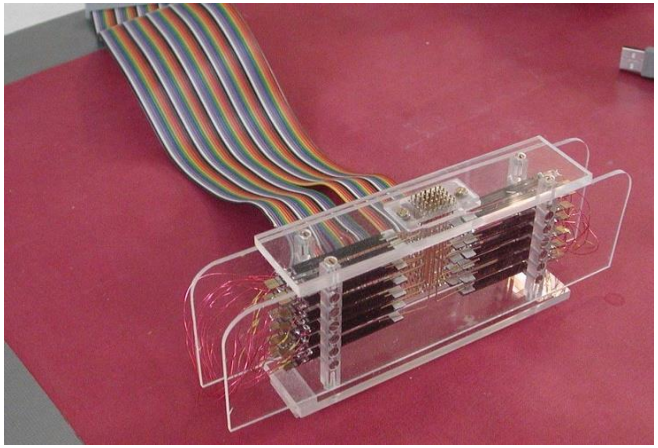


Linear motors: pin displays

- How they work:
  - Pins in an array are actuated independently
  - The actuated pins contact the surface of the skin
- Advantages:
  - Simple, readily available
  - Continuously positionable, fast movement
  - Versatile: static pressure, vibration, shapes
- Disadvantages:
  - Very difficult to pack tightly
  - Relatively expensive (several motors per device)

Example: tactile array





- Mimics complex tactile sensations
  - Stimulate the fingertips
  - Each pin has a piezoelectric actuator
- Examples
  - Top left: 100 pins over 1 cm^2, frequency range 25-400 Hz
  - Bottom left: 24 pins with 2 mm spacing, 25-500Hz

Example: Braille displays

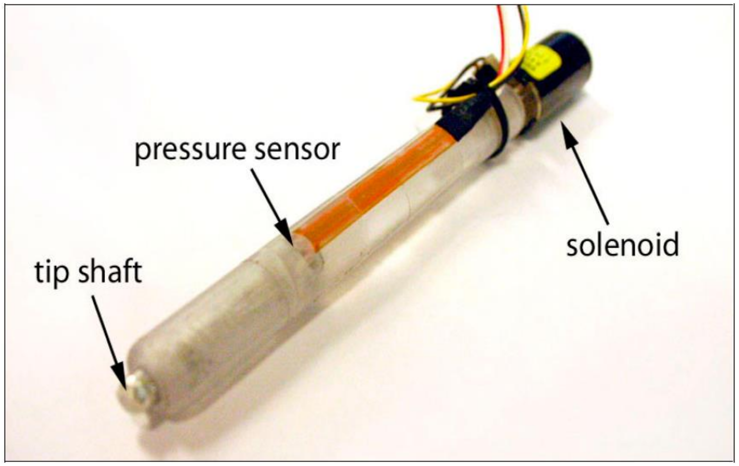
- Braille = tactile language for sensory substitution
- Visually impaired users read information by sensing different configurations of 6 or 8 pins
  - Each pin is either raised or lowered
- Also solenoids can be used

Example: tactile arrays in a mouse

- Allows the user to scan an image
  - The pins rise and fall dynamically delivering tactile stimuli to the fingertips
  - Can be used to code patterns and colours into tactile data
- VTMouse (2001)
  - Three 4x8 matrices (32 pins) put in the place of the buttons
- VTPlayer (2003)
  - Two 4x4 matrices with 16 pins

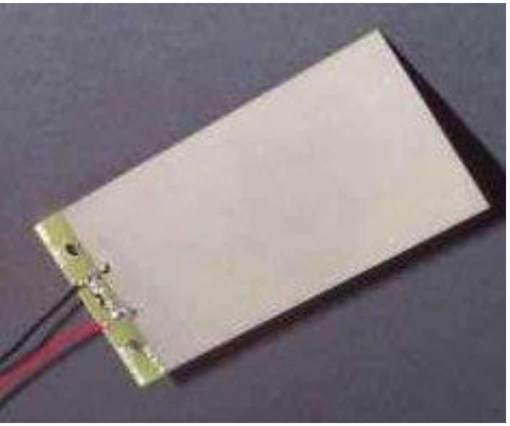
Actuators: solenoids

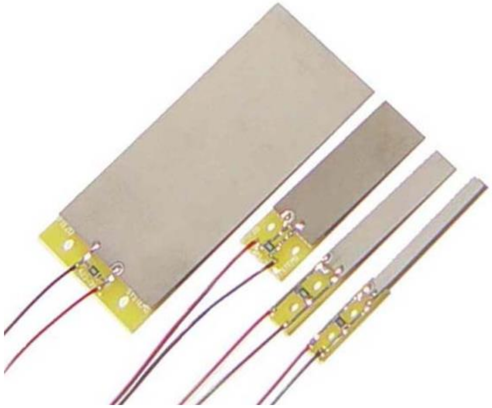
Solenoids



- Multimodal mouse by Akamatsu & MacKenzie (1996)
  - Solenoid driven pin under the left index finger that moves up & down to generate vibration
- Haptic Pen by Lee *et al.* (2004)
  - Solenoid shakes the pen by moving up and down at top of the pen

Actuators: piezoelectric actuators

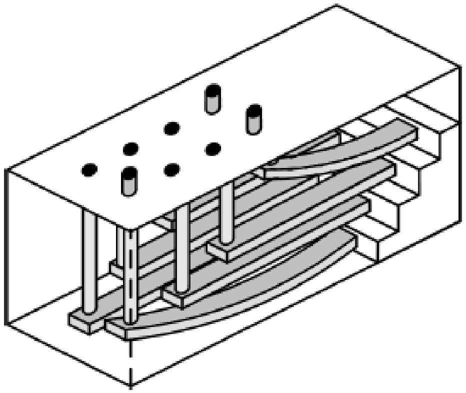


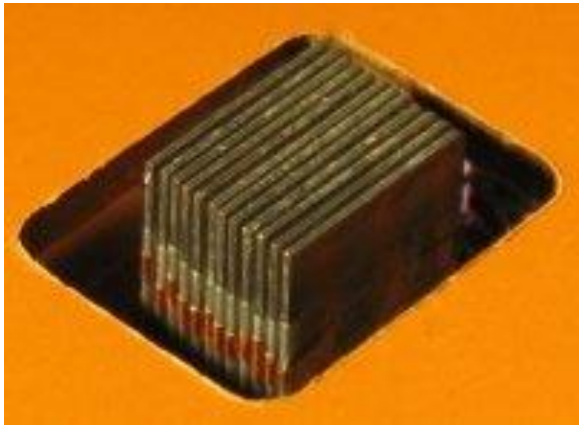


Piezoelectric actuators 1/2

- How they work:
  - Single or multilayer ceramic elements
  - An element expands/bends when voltage is applied
  - Multiple layers can be used to amplify the effect
- Properties:
  - Very large forces but small motions
  - One element typically around 0.2-1.0 mm thick
  - Resolution for frequencies ~0.01 Hz

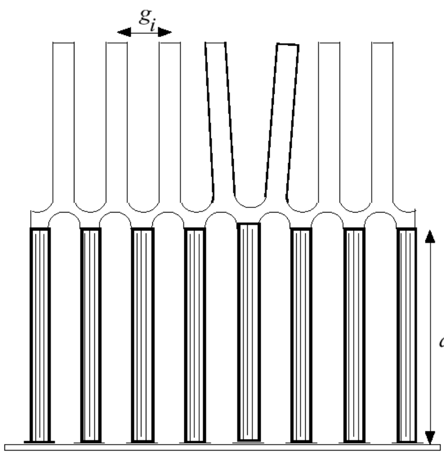
Piezoelectric actuators 2/2

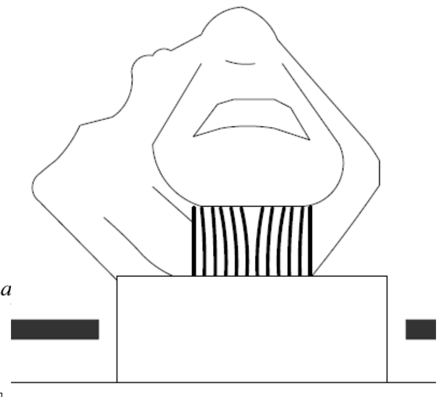




- Electromechanical device that converts electrical energy into mechanical motion
- Typically very compact as only few components are used in a complete system
  - Actuator itself can be very small

Example: STReSS & Virtual Braille Display





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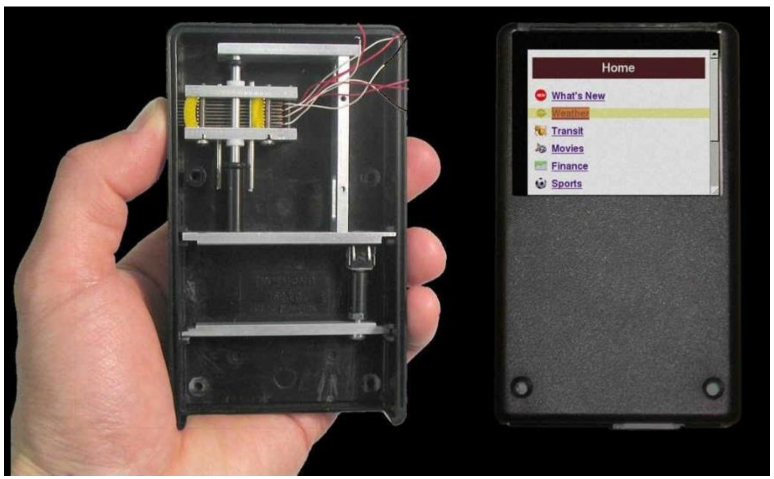
- 2D tactile display with an array of miniature actuators
  - Stimulate the fingertip at about 1 cm^2 in area
- Elements can be bended in two directions to create different sensations to the fingertip

http://www.laterotactile.com/

Example: Tactile Handheld Miniature Bidirectional (THMB)

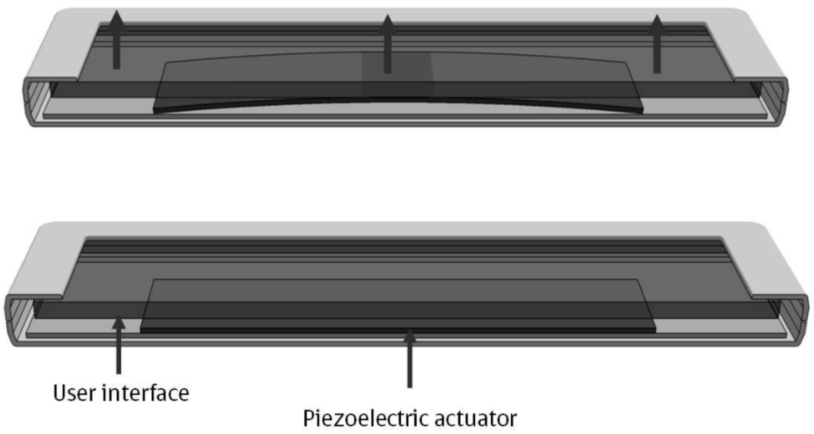


video

- THMB is an improved version of VBD miniaturized to fit inside a PDA-size case
- The handheld device includes an LCD screen that allows combining tactile and visual feedback
- THMB stimulates the user's thumb
- It is mounted on a vertical slider so that it can be dragged up and down for input

http://www.laterotactile.com/

Example: touchscreen actuation



(Laitinen and Mäenpää, 2006)

- Larger piezo elements can be used to actuate a display
- Different tactile sensations can be created by driving the piezo using different parameters
  - Click, constant vibration, …

Piezoelectric actuators: overview

- Advantages:
  - Usually small in size
  - Potentially inexpensive in large volumes
  - High frequency and static modes
  - Very fast response time
  - Low power consumption
- Disadvantages:
  - Dynamics: small displacements require accurate amplification
  - High driving voltage

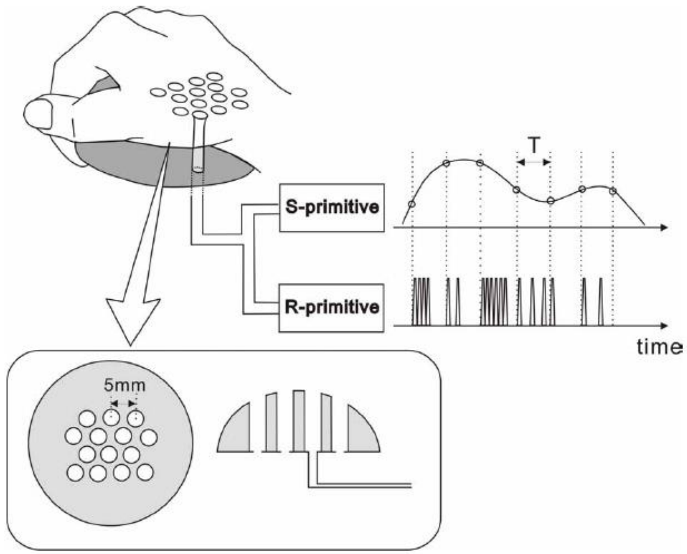
Actuators: pneumatic systems

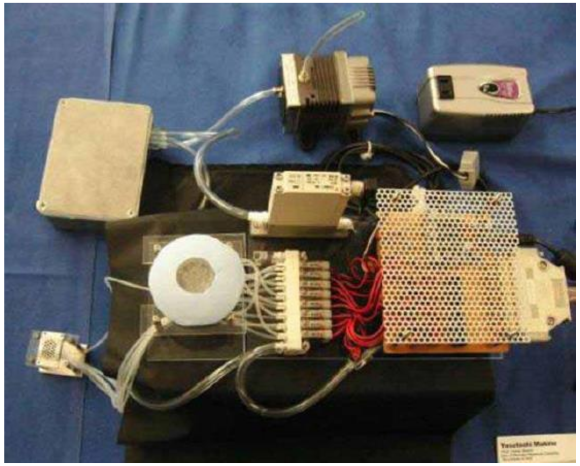
Pneumatic systems

- Three possible output modes based on skin indentation (and vibration)
  - Suction
  - Air-pressure
  - Vortices

- How it works:
  - Technologies: fillable air-pockets, air jets, suction holes
  - Vibratory rates: typically 20-300 Hz
  - Static pressure with sealed pockets

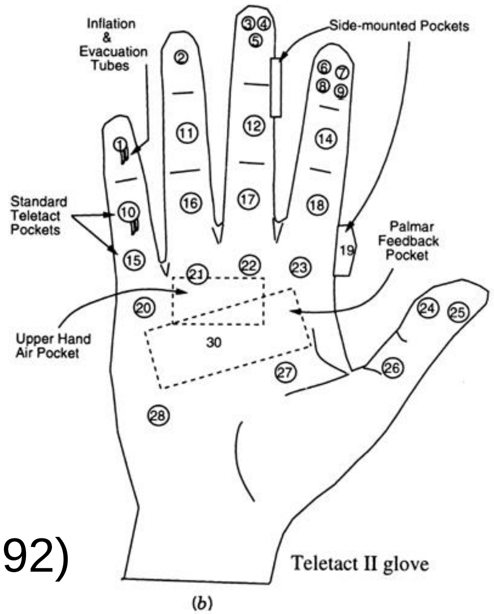
Pneumatic systems: suction



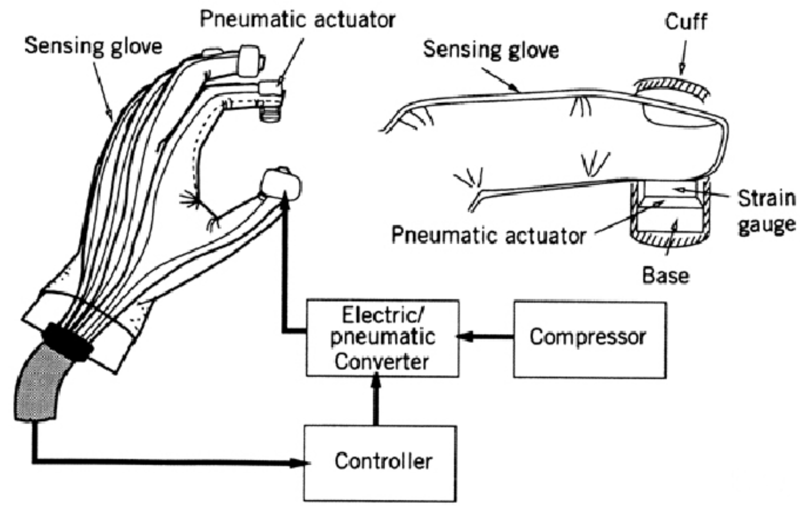


- Draws air from a suction hole creating an illusion that the skin is pushed
  - Very low spatial resolution (only appropriate for the palm)
- Two basic patterns of stimulation (large holes and small holes)
  - Need for regulation of air pressure (= lots of equipment)

Pneumatic systems: air-pressure



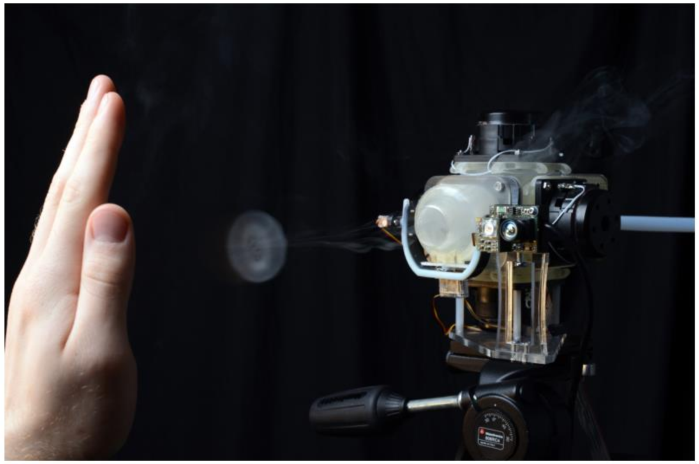
Teletact II
(Stone, 1992)



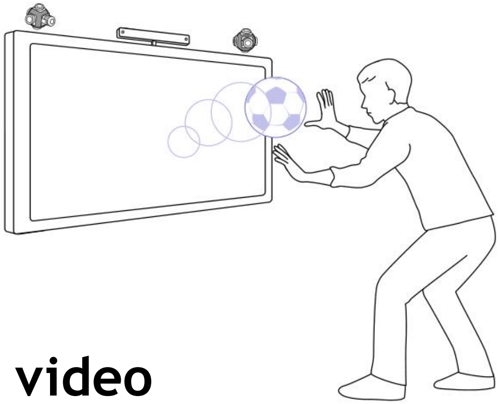
DataGlove with pneumatics
(Sato et al., 1991)

- DataGlove
  - Bandwidth of 5 Hz, amplitude & frequency modulated
- Teletact II
  - 29+1 air pockets (40 tubes to control the air-pressure)
  - Object slippage (fingers) + force feedback (palm)

Pneumatic systems: vortices



AIREAL (Sodhi et al., 2013)



video

- Emits a ring of air called a vortex that can be felt in mid-air
  - Controlling a flexible nozzle allows for directed sensations
  - Operating distance of roughly one meter

Pneumatic systems: overview

- Advantages:
  - Tubing make it possibly to take the bulky part away from point of application
  - Pressure can be more appropriate for some applications than pins or vibrating motors
  - Can mimic skin-slip (with multiple inflated pockets)
  - Vortices can enable mid-air interaction

- Disadvantages:
  - Previously has required bulky parts (air compressor or motor-driven pistons)
  - Not really portable, can be very noisy
  - Difficult to display sharp edges or discontinuities

Actuators: shape-memory alloys

Shape-memory alloys

- Metals that "remember" their geometry
  - Restores its original geometry when heated
  - Usually temperature change of about 10°C is necessary to initiate the phase change
- How it works:
  - Expands (and heats up) when current runs through it
  - Contracts when cools down
  - Stimulates the skin with vibration (expand-contract cycles)

Shape-memory alloys

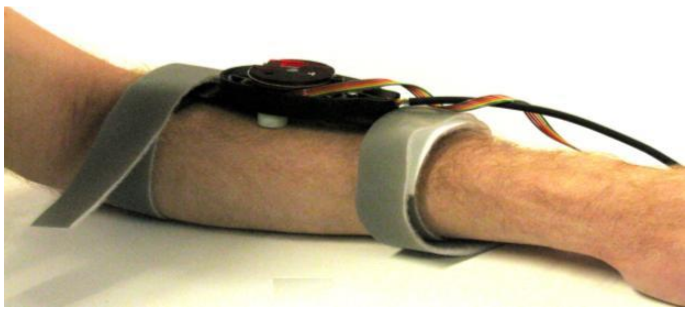
Tactile Display based on Shape Memory Alloy (MIT Touchlab)

Lumen: A Shape Changing Display

video

Tactile displays: skin stretch

Skin stretch

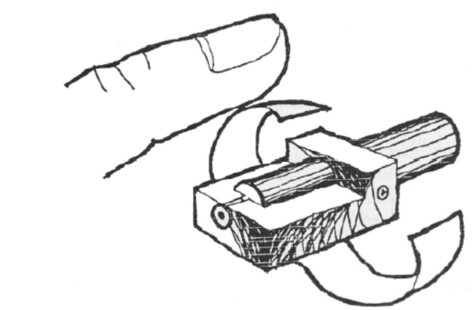


(Bark et al., 2010)

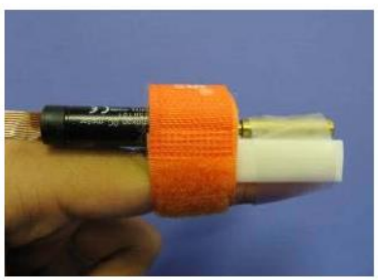
video

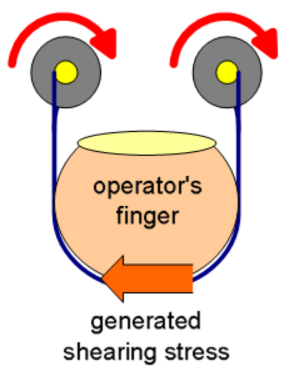
- Rotational skin stretch
- What happens:
  - Forces are applied to skin for displacement
  - Contact forces are perceived as stretching of the skin
- Applying skin stretch is being investigated as an alternative to vibrotactile feedback

Friction: skin-slip display



(Chen and Marcus, 1994)





(Minimizawa et al., 2007)

- Micro skin-stretch
  - Motor driven smooth cylinder or belt strapped against finger
  - When rotates, stimulates the mechanoreceptors
- Felt as a sensation of slip
  - Grasp simulations: causes the user to increase grip force
  - Often used to append force feedback displays

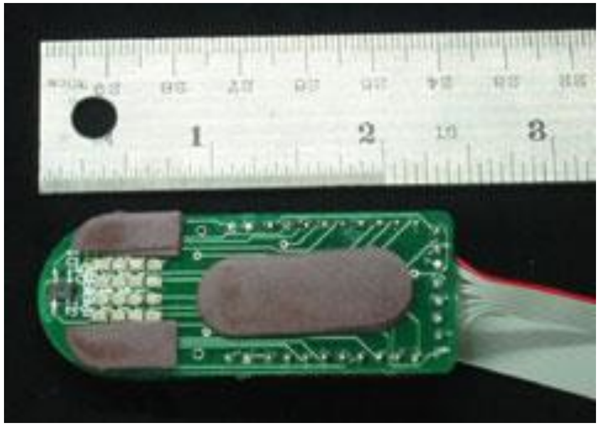
Tactile displays: electrotactile stimulation

Electrotactile stimulation

- Electrotactile or electrocutaneous stimulation is not widely accepted to consumer use
  - Stimulate receptors and nerve endings with electric charge passing through the skin
  - Often sudden bursts give an "invasive" impression
  - “Square waves” can be easily felt as too strong stimuli and they keep tickling the nerves
  - The sensitivity to electrical stimulation varies greatly between and within individuals (e.g., sweating & pressure affect the sensation)

- Used mostly in research prototypes and for rehabilitation purposes

Example: SmartTouch



video

http://www.star.t.u-tokyo.ac.jp/projects/smarttouch/

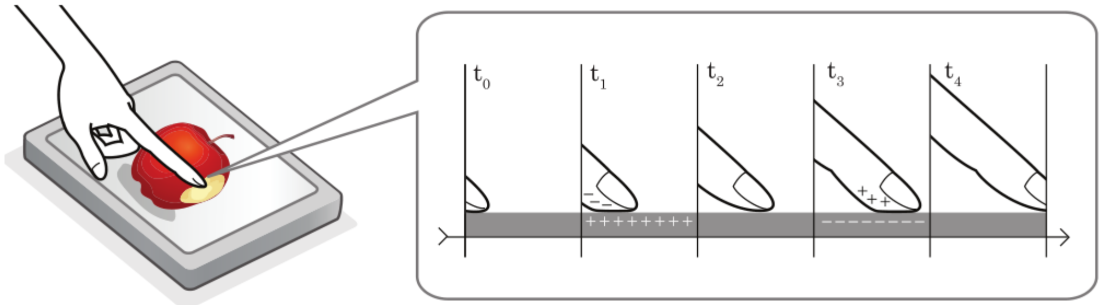
- Tactile display to mimick realistic skin sensation
- Two layers
  - Top layer: 4x4 array of stimulating electrodes
  - Bottom layer: optical sensors
- Visual information is captured by the sensors and displayed through electrical stimulation
  - E.g., the black stripes on a paper are perceived as bumps

Tactile displays: electrovibration

Electrovibration

- Contrary to electrotactile stimulation, in electrovibration there is no passing charge
  - Electrovibration is based on electrostatic friction between an object and user's skin
  - Can be felt as vibration
- Electrovibration requires no moving actuation parts and is therefore relatively easy to add to existing devices

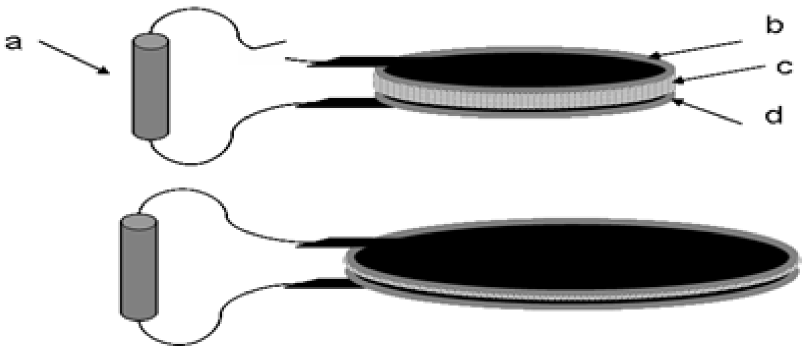
Example: TeslaTouch



- Moving a finger across a touch surface generates electrovibration (Bau *et al.*, 2010)
  - Based on a transparent electrode sheet placed under the touch surface, electrodes excited with a periodic signal
  - Electrostatic attraction between the electrode and finger is perceived as vibration
- Senseg has been developing similar technology

Tactile displays: dielectric elastomer actuators

Example: Dielectric polymer



video

- Uses a dielectric polymer film (c) between two electrodes (b & d)
  - Voltage causes the electrodes to attract each other
  - The film contracts in thickness and expands in area
- Runs at around 1000 V (DC) at very low current
  - Require less power compared to traditional vibration motors and piezo actuators

Actuators: ultrasonic transducers

Example: Ultrasonic transducer

video

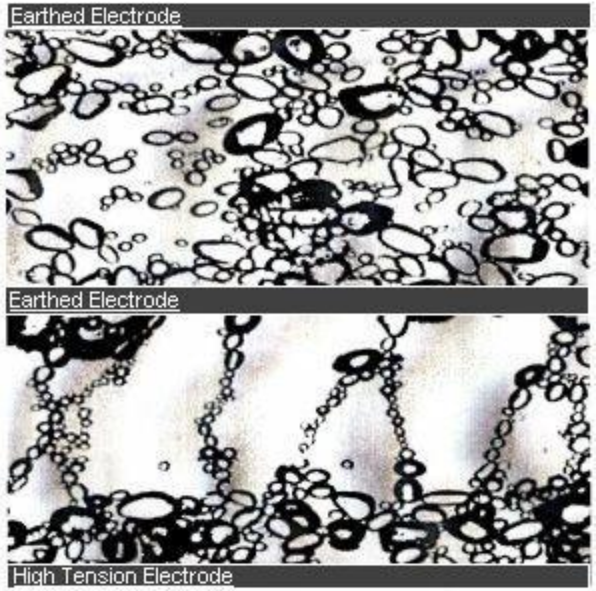
- Based on acoustic radiation pressure
  - A prototype consists of 324 airborne ultrasound transducers controlled individually
  - The feedback can be felt about 20 cm over the surface
- Although the produced force is weak to feel constant pressure, it is sufficient for a vibratory sensation

Actuators: electrorheological fluids

Example: Electrorheological fluids

(a)

(b)



video

- Viscosity of liquid changes into semi-solid when electric current is applied (pic. a -> b)
  - Semi-solid liquid can be felt as a more resistive surface
  - Change in viscosity is proportional to the current
  - From a -> b within milliseconds
- Can be used to simulate different surface frictions
  - Also with force-feedback

Actuators: Thermal actuators

Example: Peltier elements

- Peltier elements are based on two sides controlled using DC current
  - When one side gets cooler, the other gets hotter
  - Human neutral zone 28-40°C
- Cold stimuli are more perceivable and comfortable than warm stimuli (Wilson et al., 2011)
  - Faster-changing stimuli are easier to detect but less comfortable

Thermal systems: overview

- Advantages:
  - Silent technology
  - Usable in situations with environmental vibration
- Disadvantages:
  - Environmental temperature affects the sensation
  - Not particularly expressive (i.e., the range of different sensations is limited)
  - Temperature variations must be controlled properly so that the stimulation is not uncomfortable