Biomechatronics

Delft University of Technology, 2007

Wb 2432

Artificial Sensory Systems

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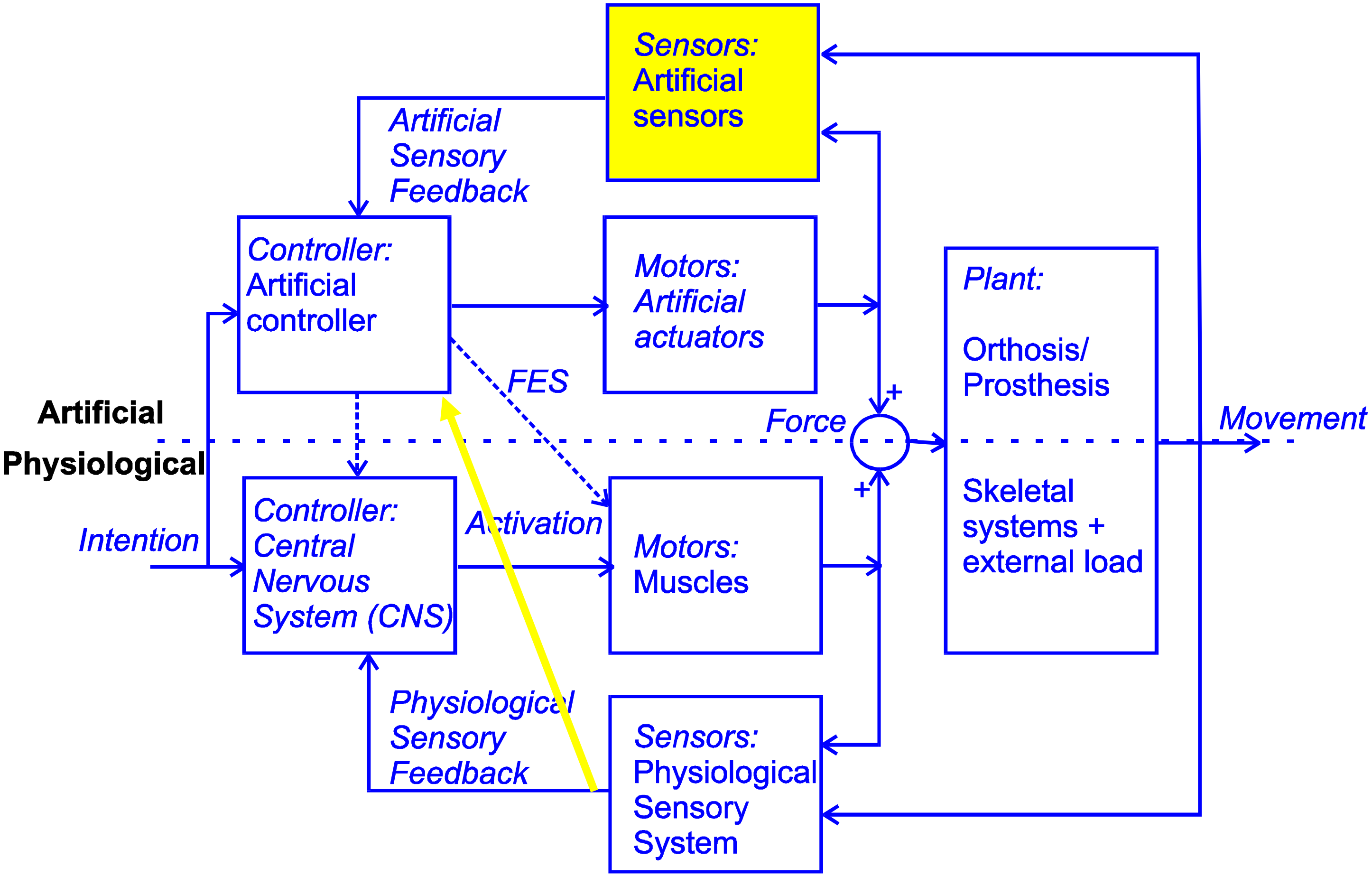
TUDelft

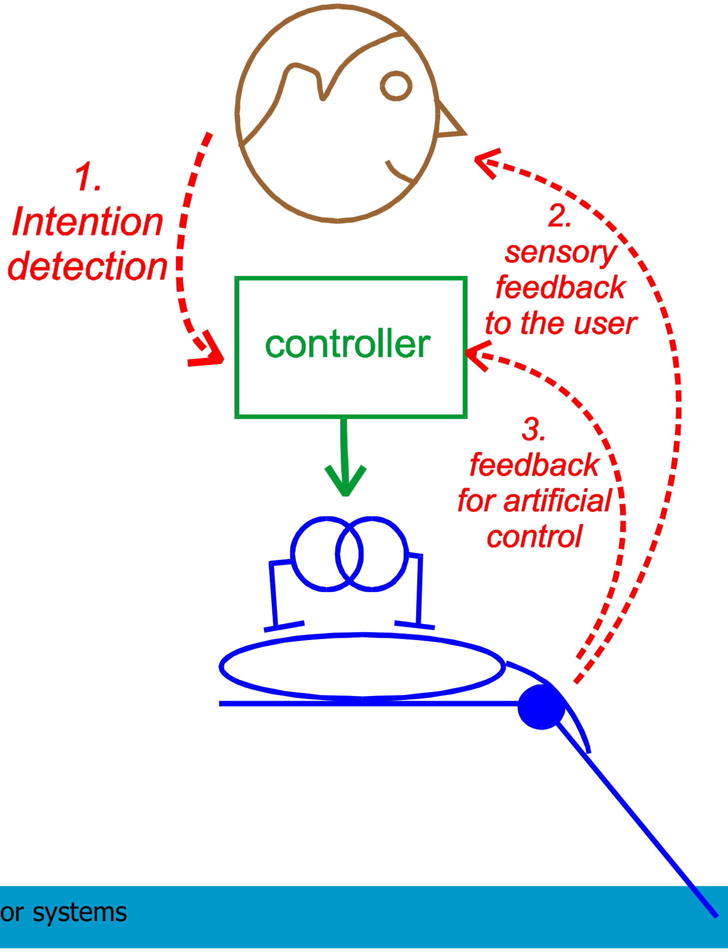
Technische Universiteit Delft

Sensing for assistive motor systems



Sensing for assistive motor systems

why?



1. Intention detection

controller

2. sensory feedback to the user

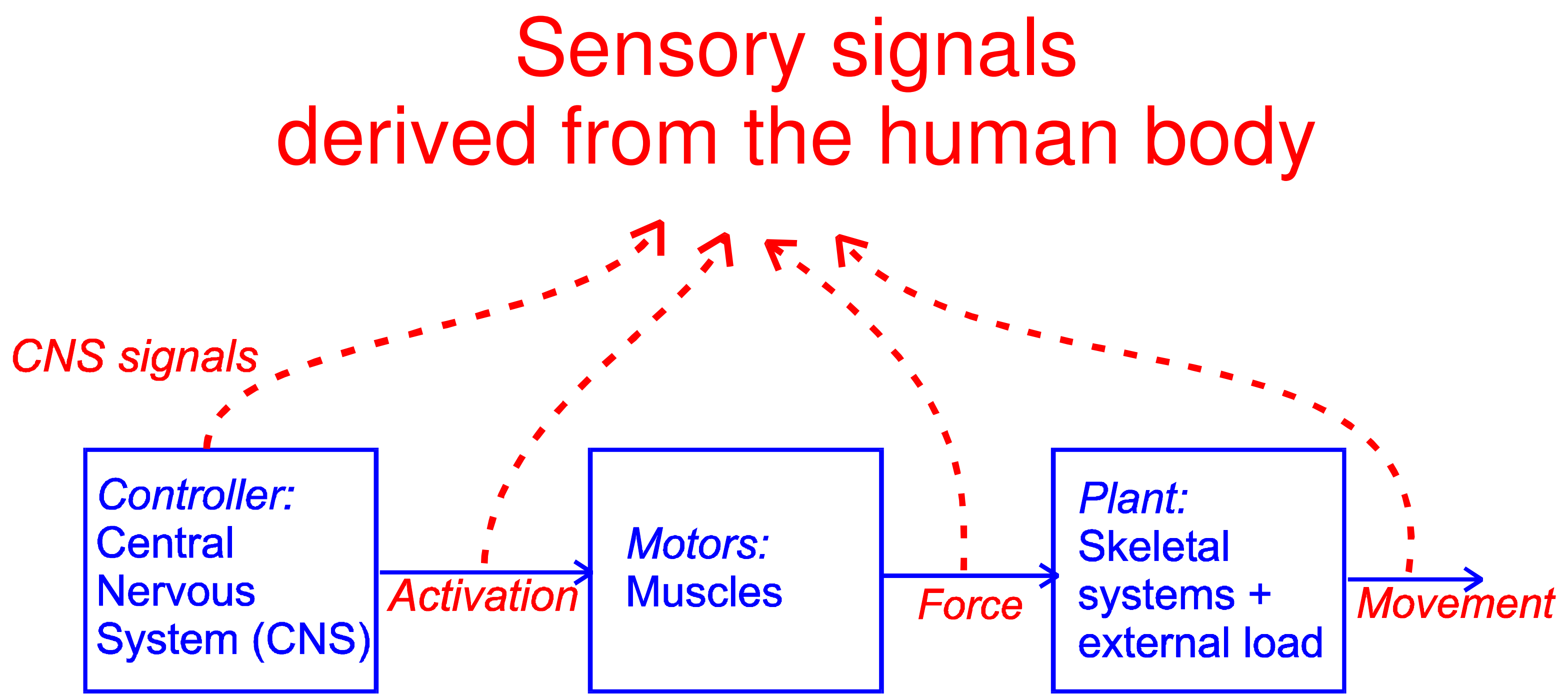
3. feedback for artificial control

TU Delft

Intention detection

- Directly from the brain: Human – computer interfacing (HCI)
- EMG recordings
- Behaviour recordings
  - Motions
  - Forces
- Direct interaction: Buttons, etc.

Sensing for assistive motor systems



Sensory signals
derived from the human body

CNS signals

Controller:
Central Nervous System (CNS)

Activation

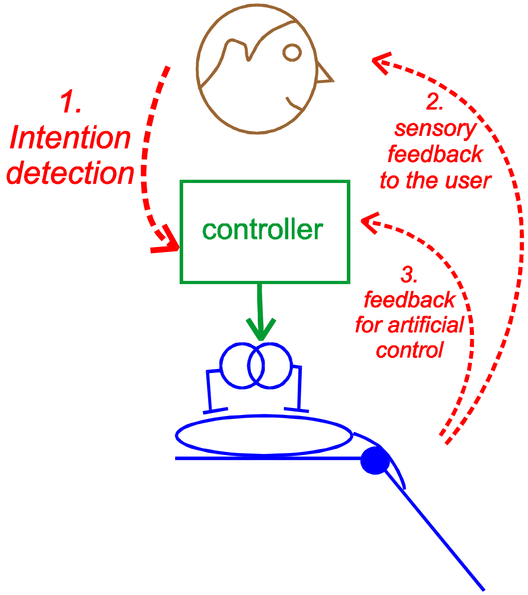
Motors:
Muscles

Force

Plant:
Skeletal systems + external load

Movement

Sensing for assistive motor systems



1\. Intention detection

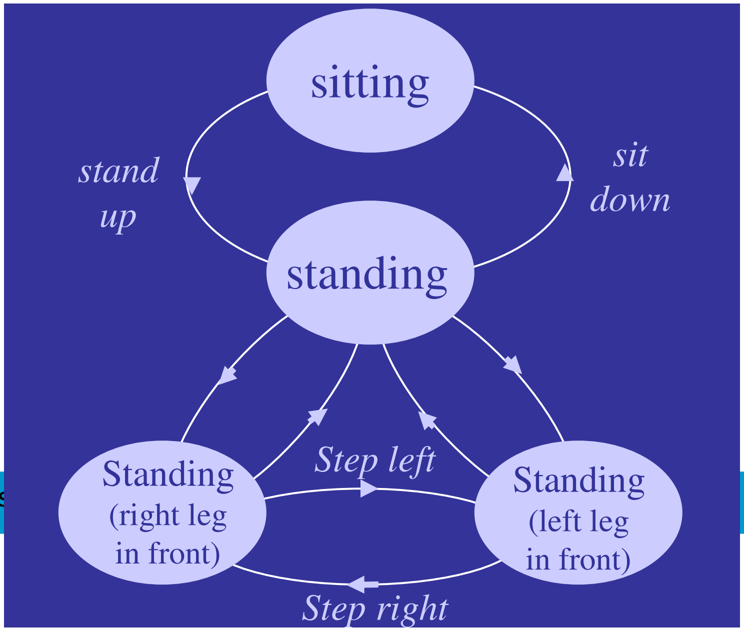
2\. sensory feedback to the user

controller

3\. feedback for artificial control

Angle recording

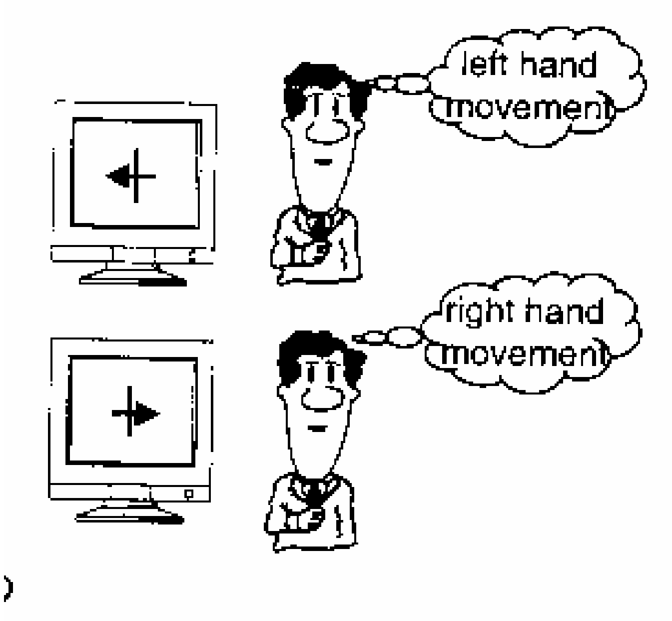
Buttons in crutches

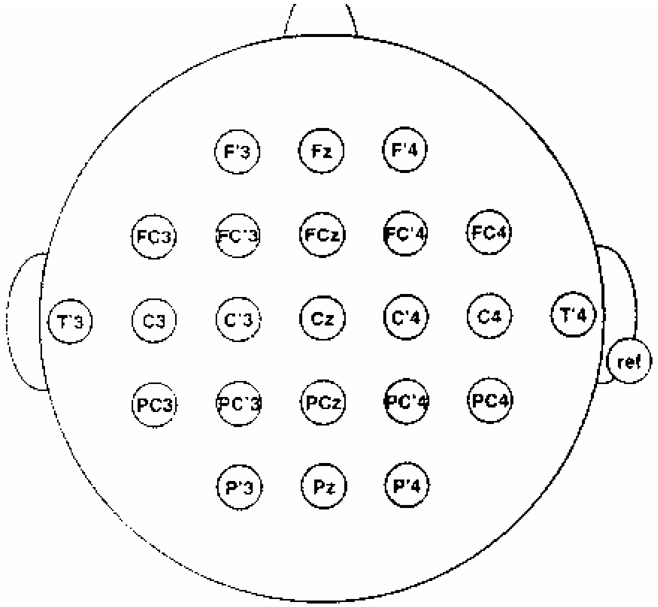


Measure physiological signals

Brain signals EEG

Intention detection

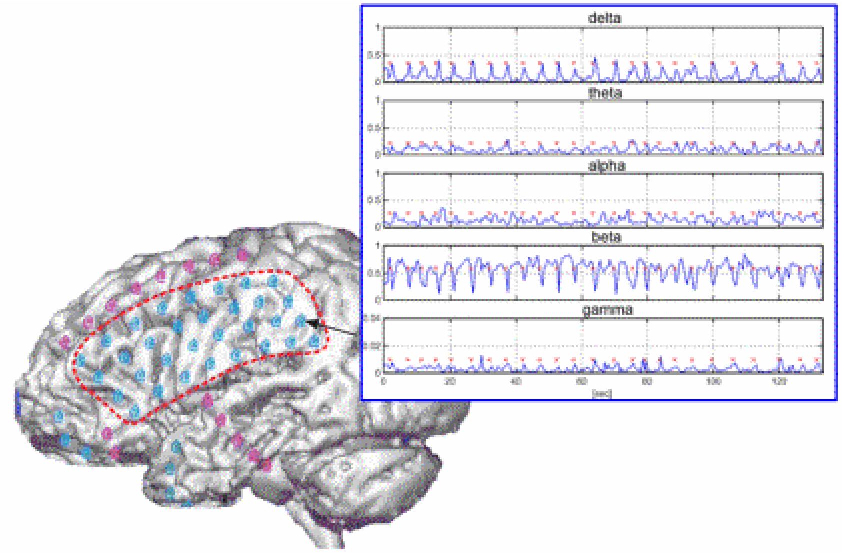




Think *left* or *right*

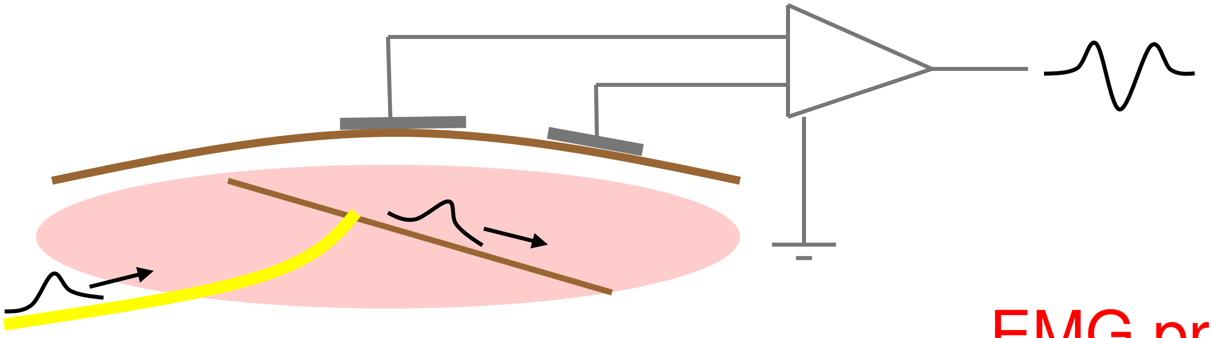
Pfurtscheller et al.
(Graz)

Direct Brain Interface (DBI)

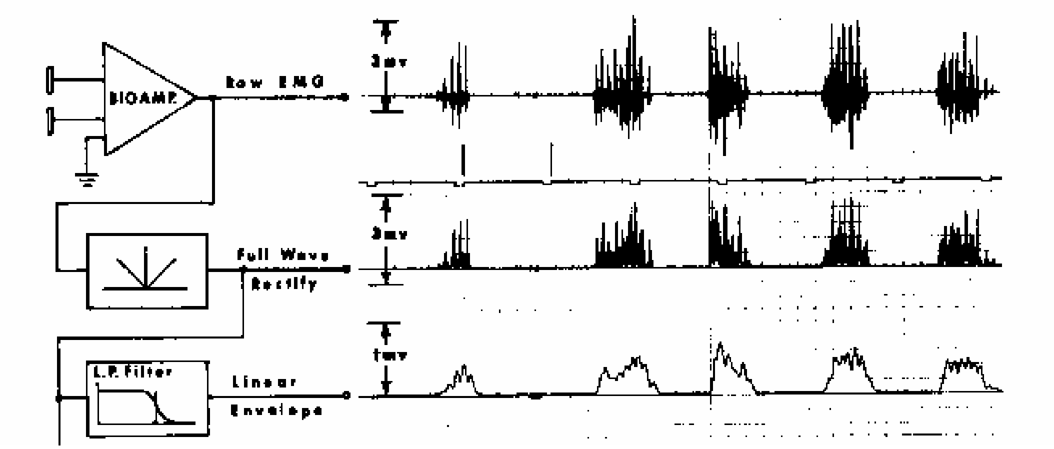


Measure physiological signals

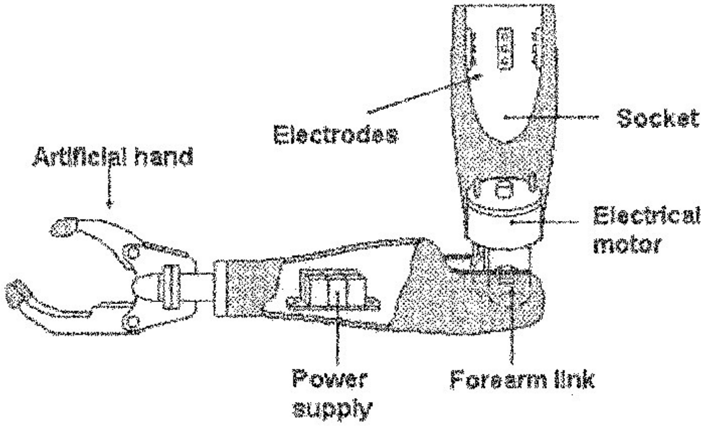
muscle activation: EMG

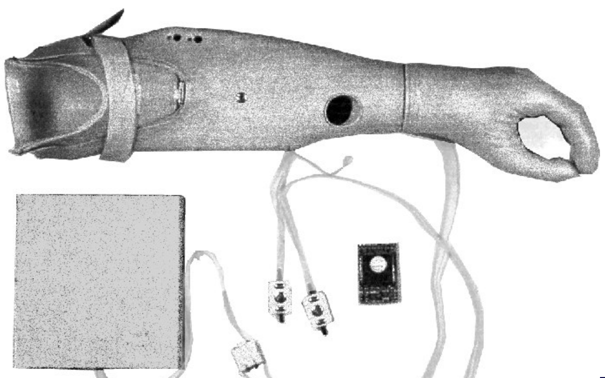


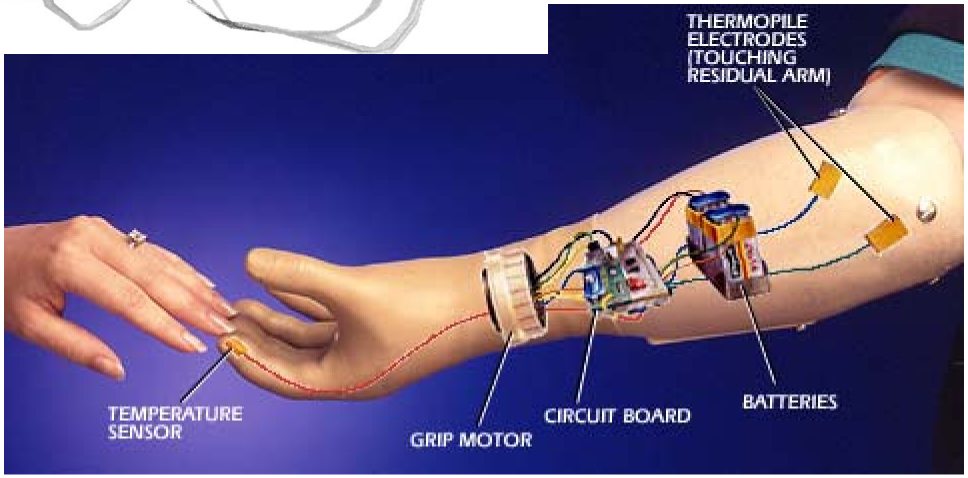
EMG processing



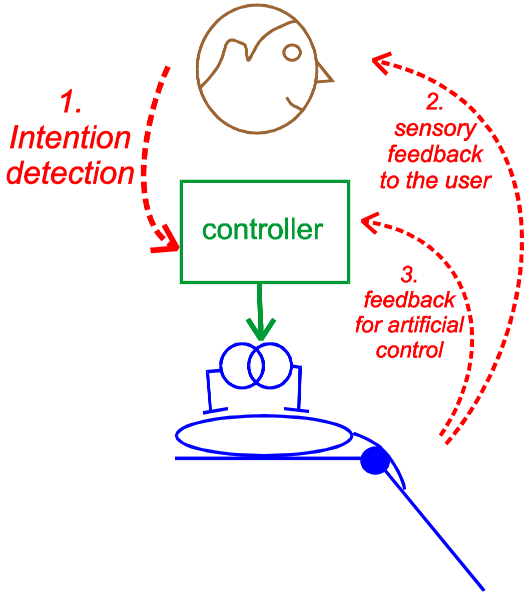
Myo-electric prosthesis







Intention detection



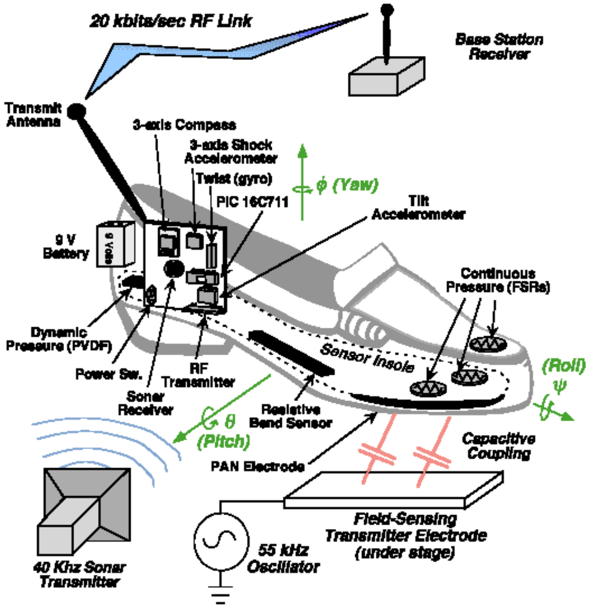
1. Intention detection

2. sensory feedback to the user

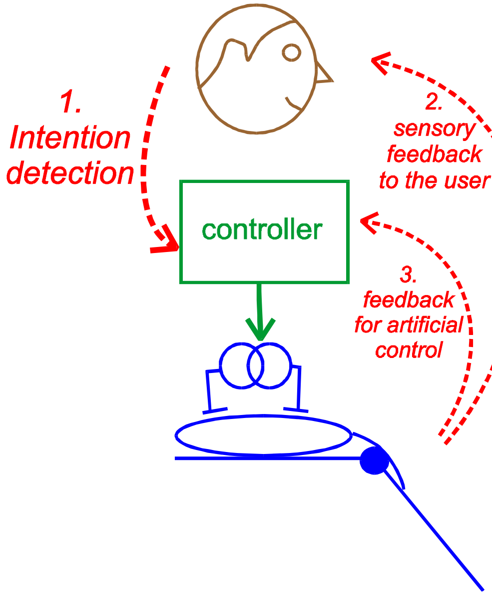
controller

3. feedback for artificial control

MIT media labs
expressive footwear:
Measuring motions and forces



Intention detection



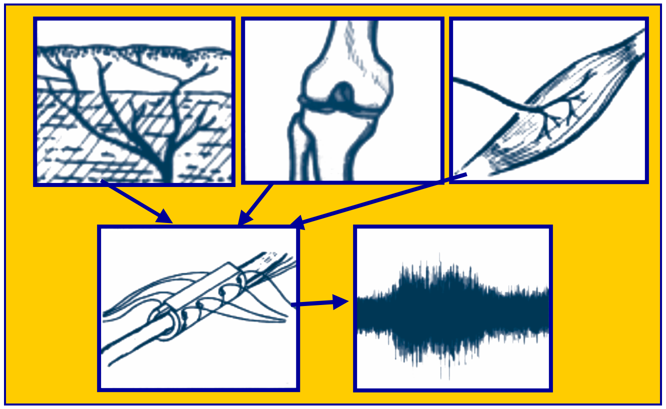
MIT media labs
expressive footwear

Byron in action

Sensing for assistive motor systems

- use body's own sensors and CNS signals
- artificial sensors

physiological sensors



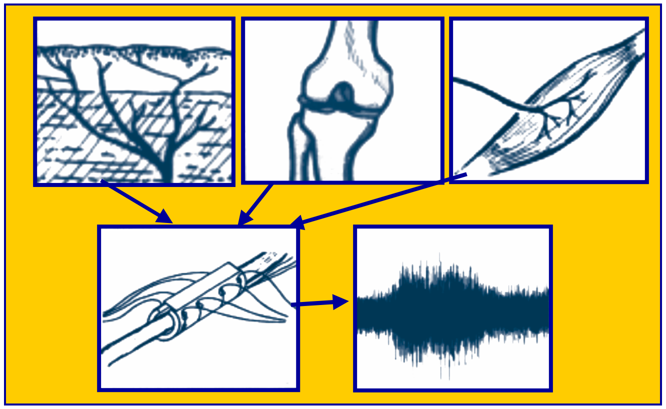
(Sinkjaer et al., Aalborg Universtiy)

Using body's own sensors

- Measure sensory signals at nerves
- Couple information back to artificial controller
  - Example: Drop-foot stimulator

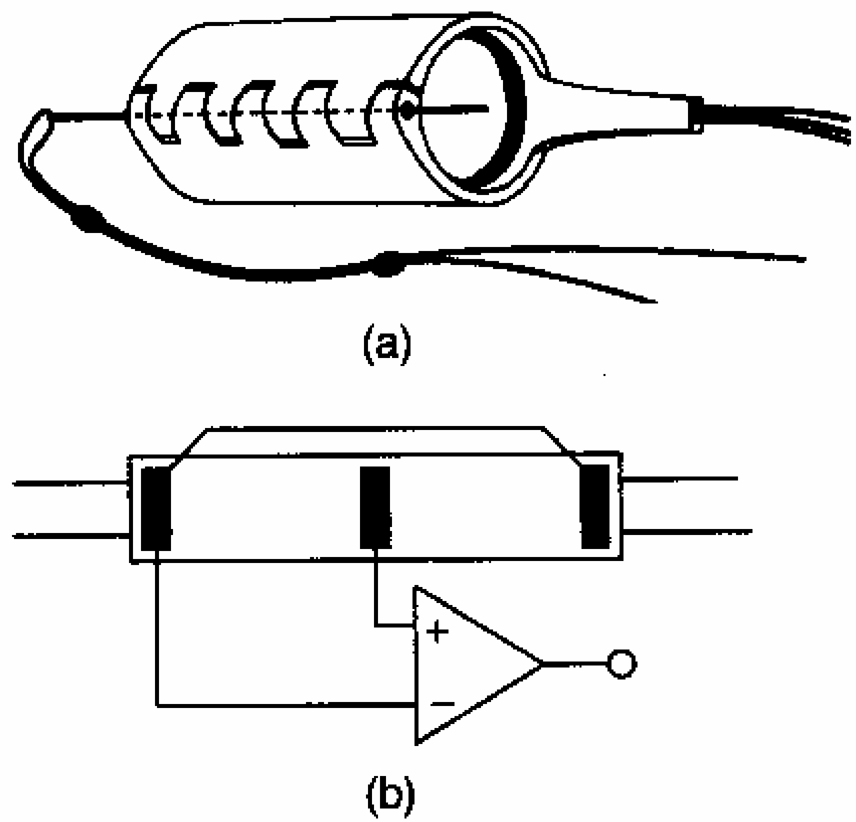
Measure body's own sensory signals

physiological sensors



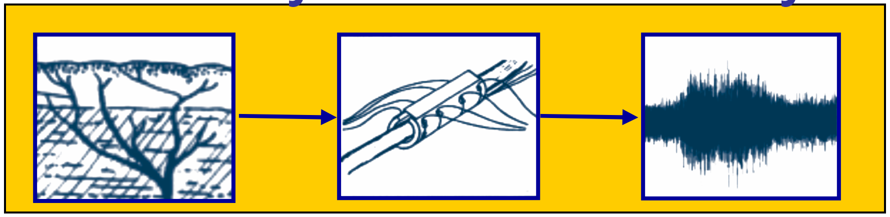
(Sinkjaer et al., Aalborg Universtiy)

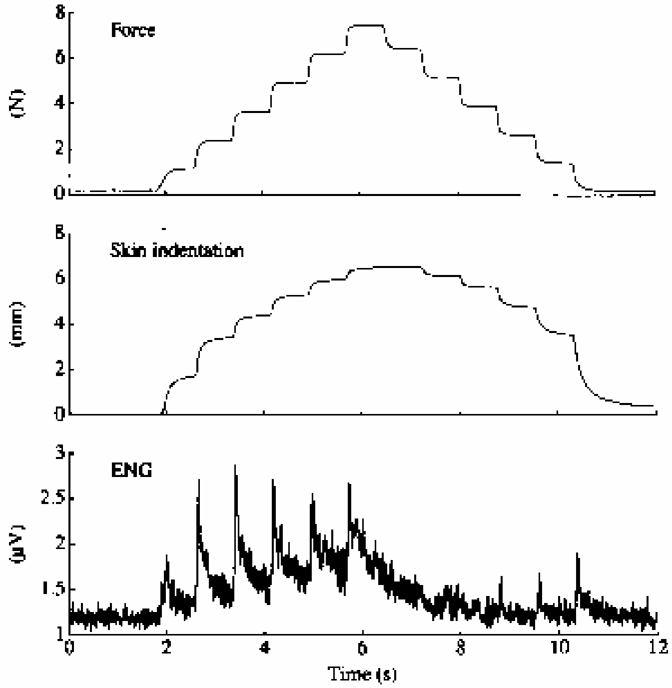
tripolar measurement cuff



Measure body's own sensory signals

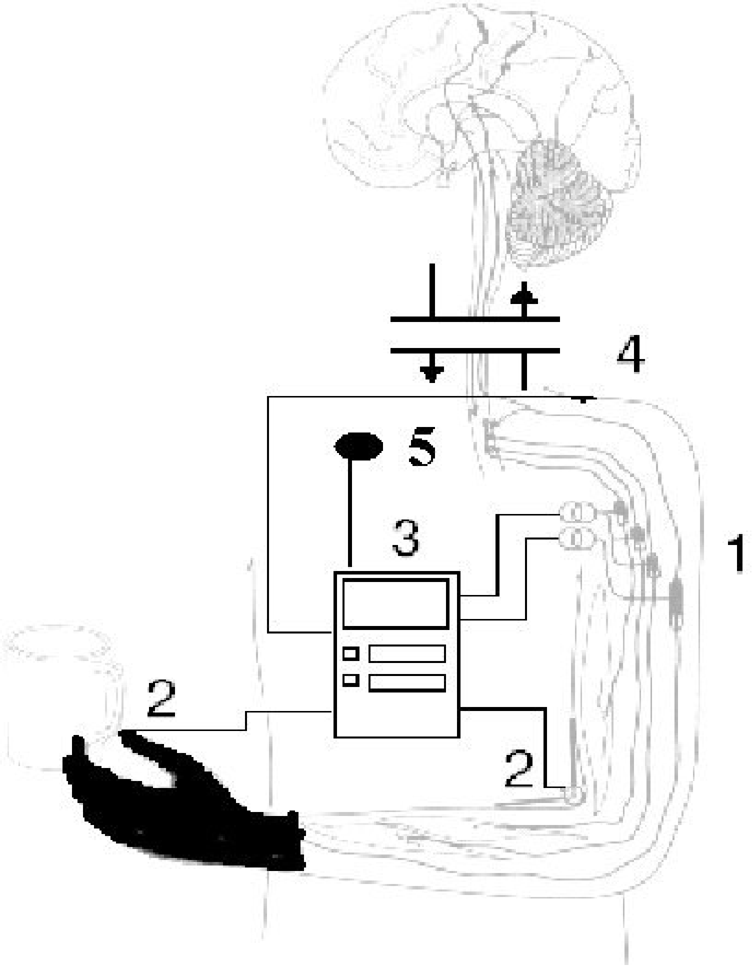
skin pressure
sensors





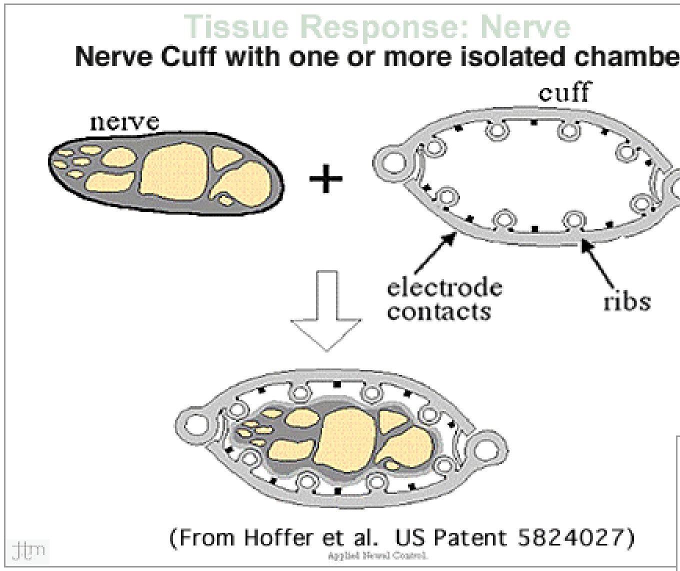
*University
of Aalborg*

Skin sensors for grasping



1. Muscle stimulation
2. Neural sensing of tactile stimuli
3. Controller
4. Spinal cord lesion
5. Intent detection

Nerve cuff electrodes

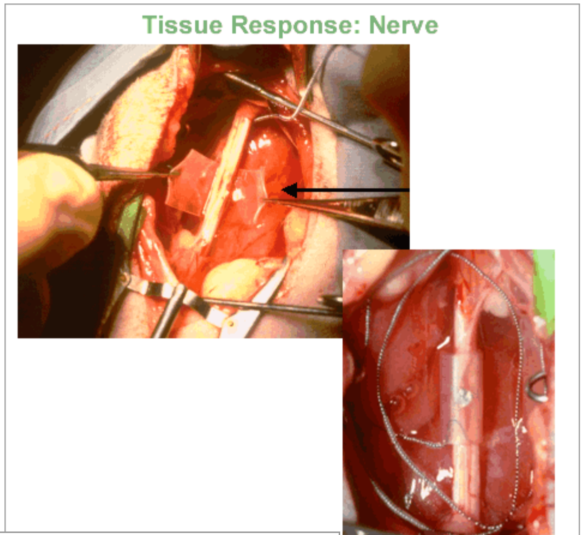


Tissue Response: Nerve

Nerve Cuff with one or more isolated chambers

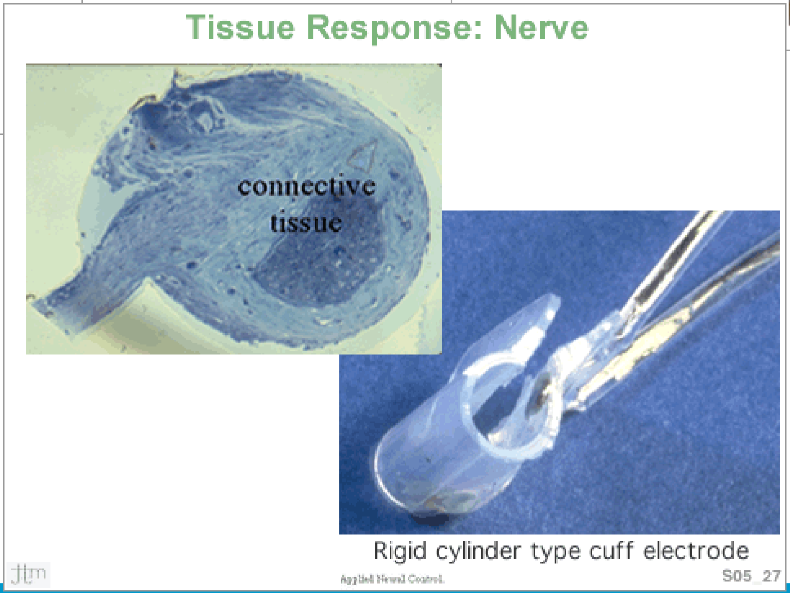
(From Hoffer et al. US Patent 5824027)

Applied Neural Control.



Tissue Response: Nerve

S05_31



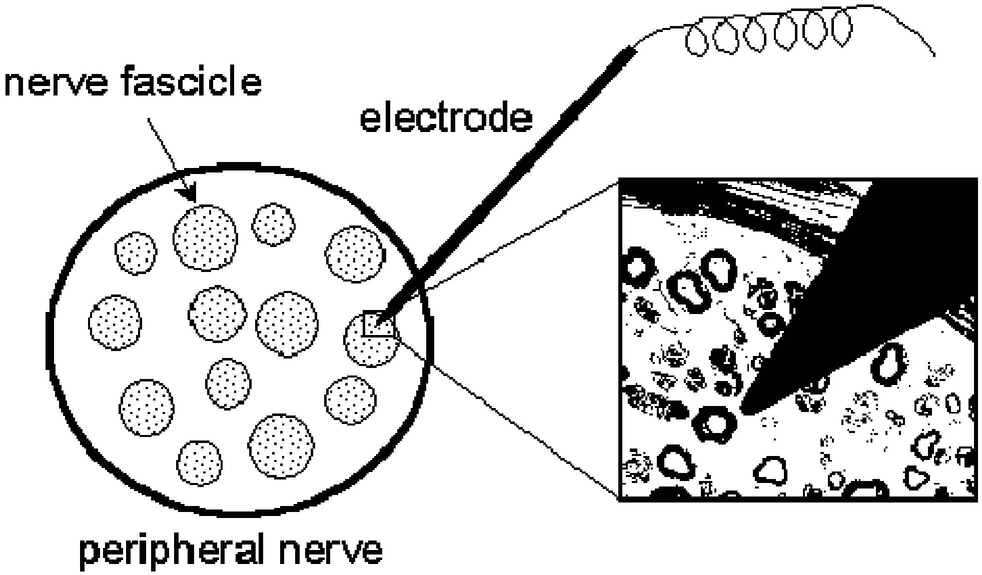
Tissue Response: Nerve

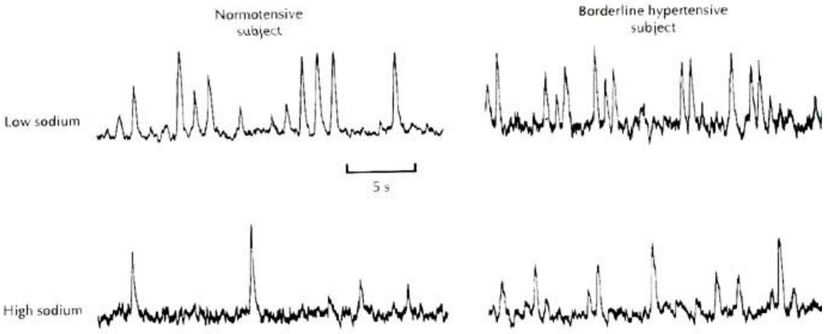
Rigid cylinder type cuff electrode

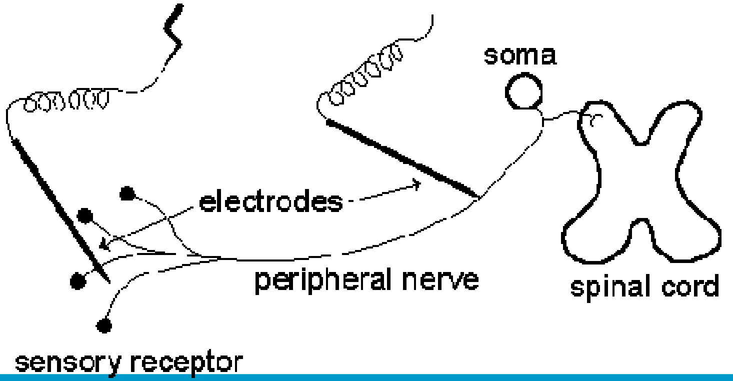
Applied Neural Control.

S05_27

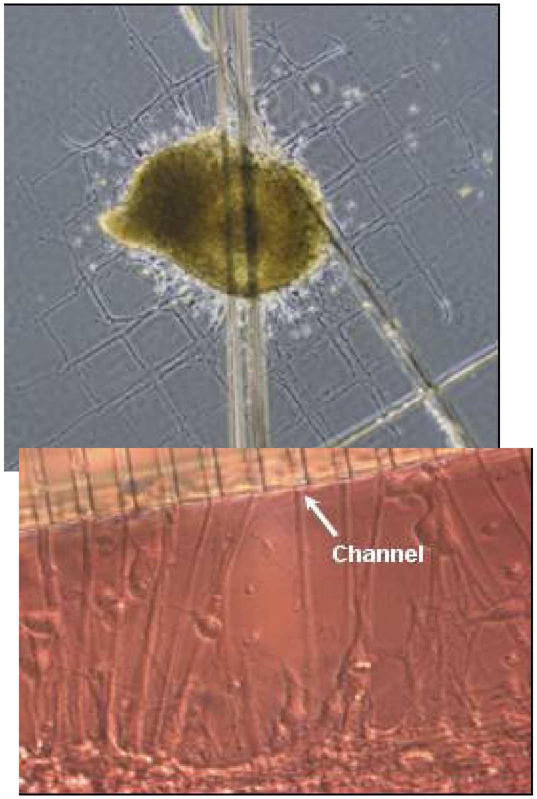
Micro-neurography



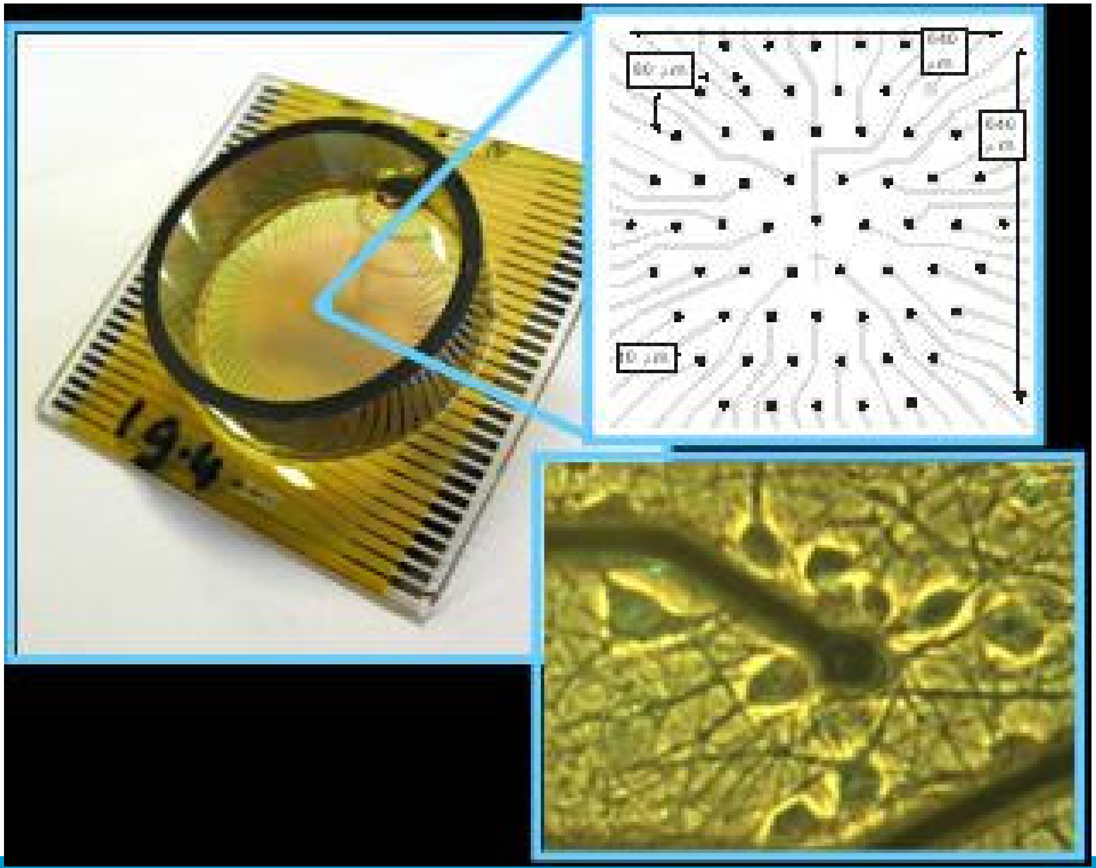




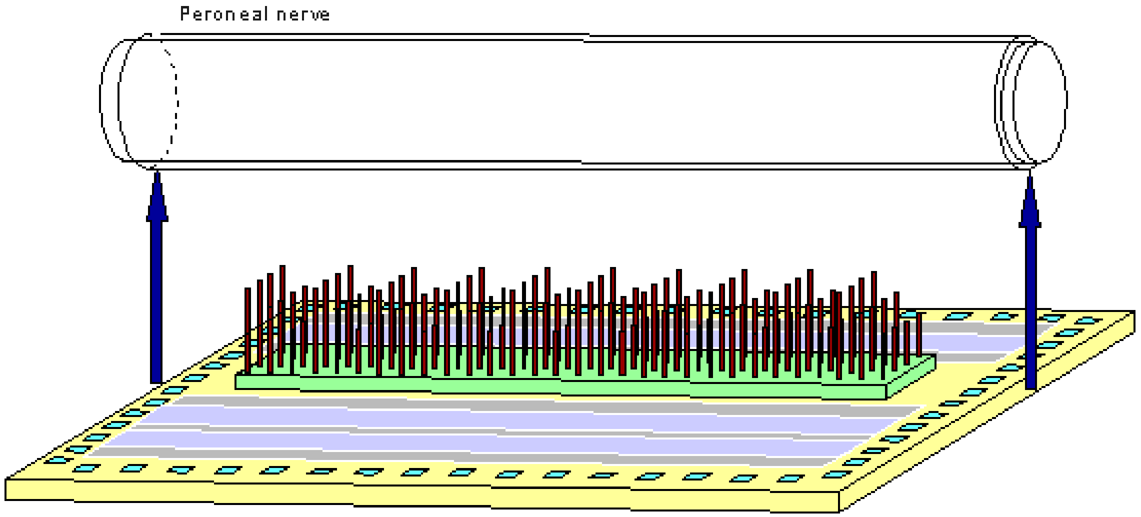
Neural Networks on a Chip



Neural Networks on a Chip (Marani, Rutten et al., Un. Of Twente)



Intraneural electrode-array

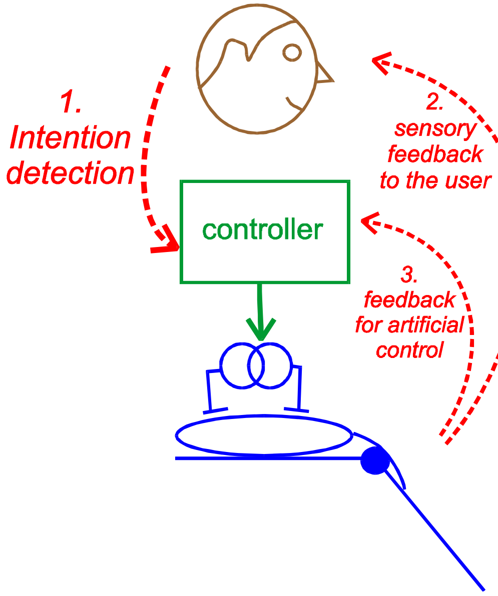


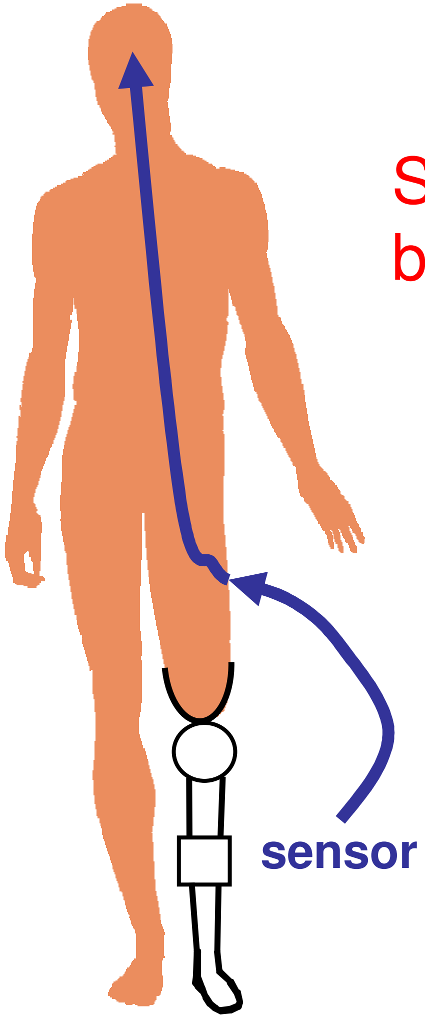
Rutten et al., University of Twente

Artificial sensors to replace body's own sensors

- Using artificial sensors
- Direct stimulation of nerve fibers, or through skin sensors
  - Encoding of information
  - Stimulation frequencies and amplitudes
  - Training of human subjects
- Examples
  - Prosthesis users
  - Cochlear implants
  - Visual implants

Sensing for assistive motor systems

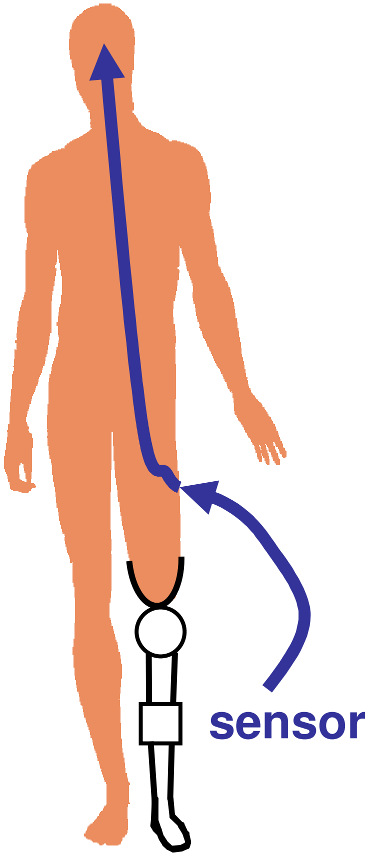




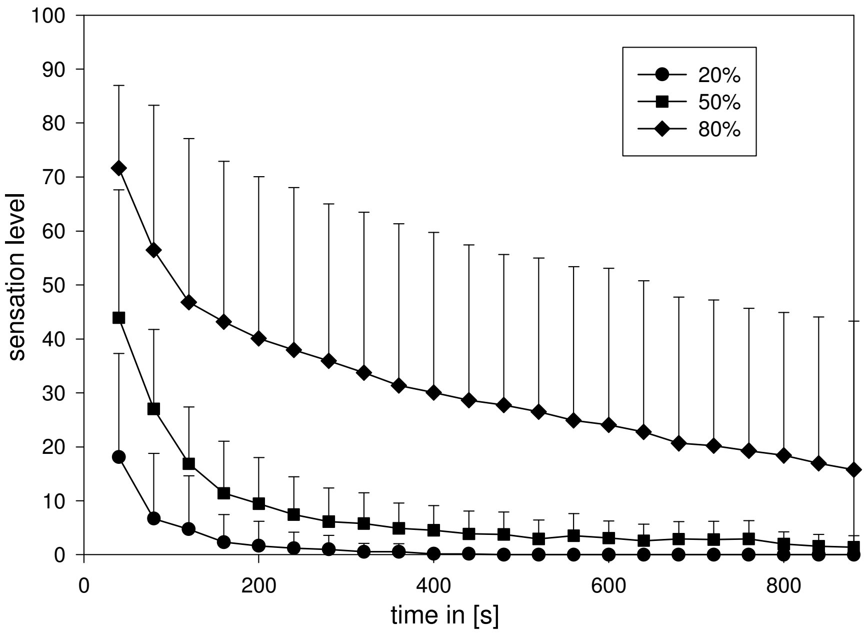
Sensory feedback to the user
by stimulation of skin sensors

Sensing for assistive motor systems

Sensory feedback to the user by stimulation of skin sensors

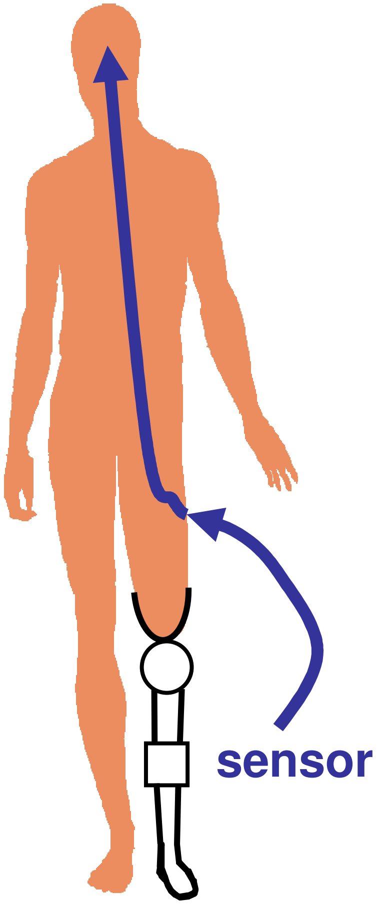


Influence of stimulation level on sensation

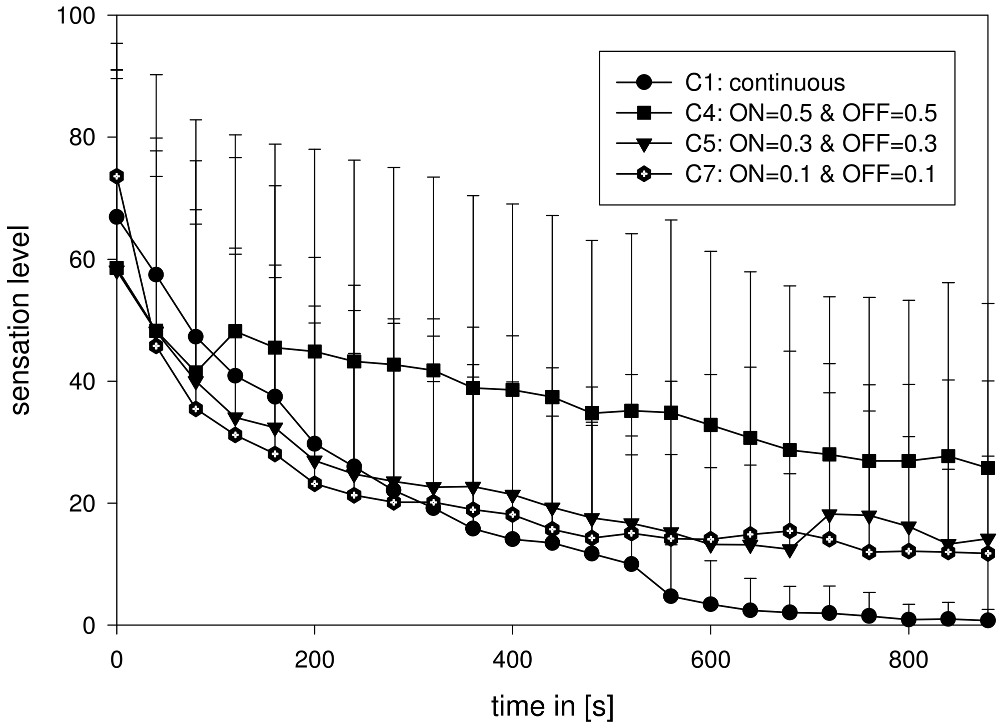


Sensing for assistive motor systems

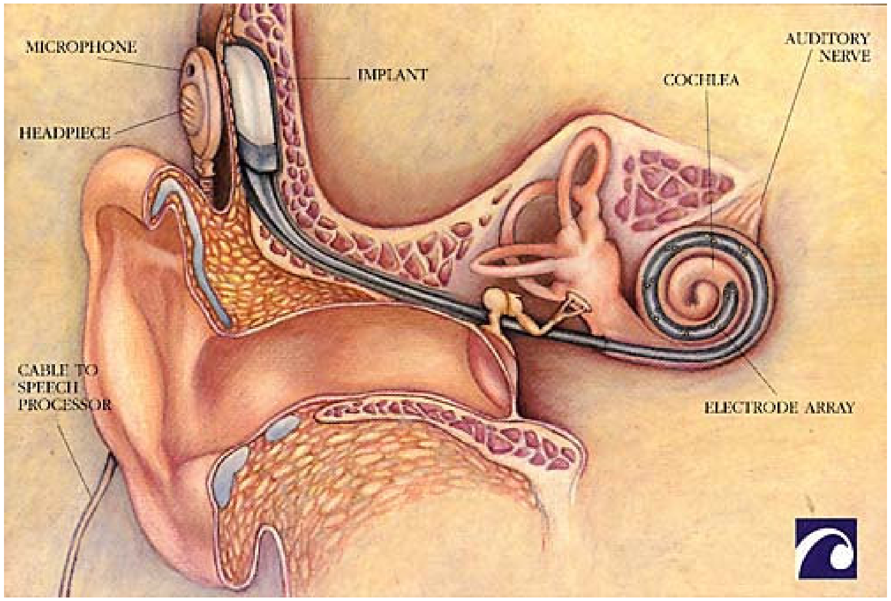
Sensory feedback to the user by stimulation of skin sensors

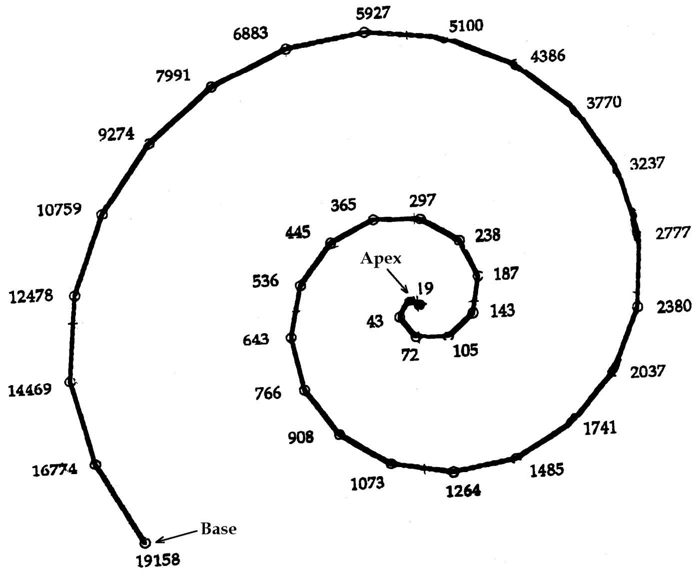


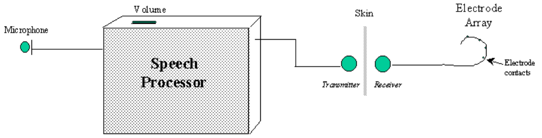
Influence of intermittent stimulation on sensation

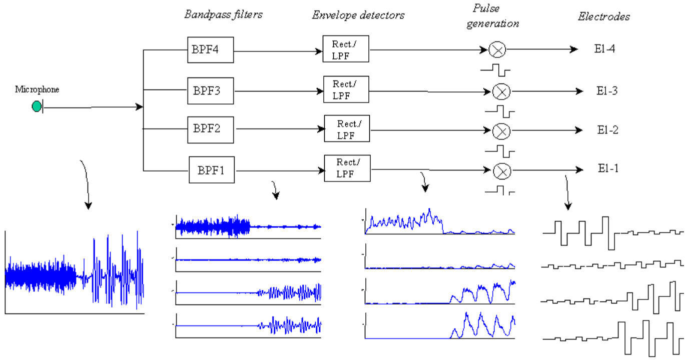


Cochlear implants





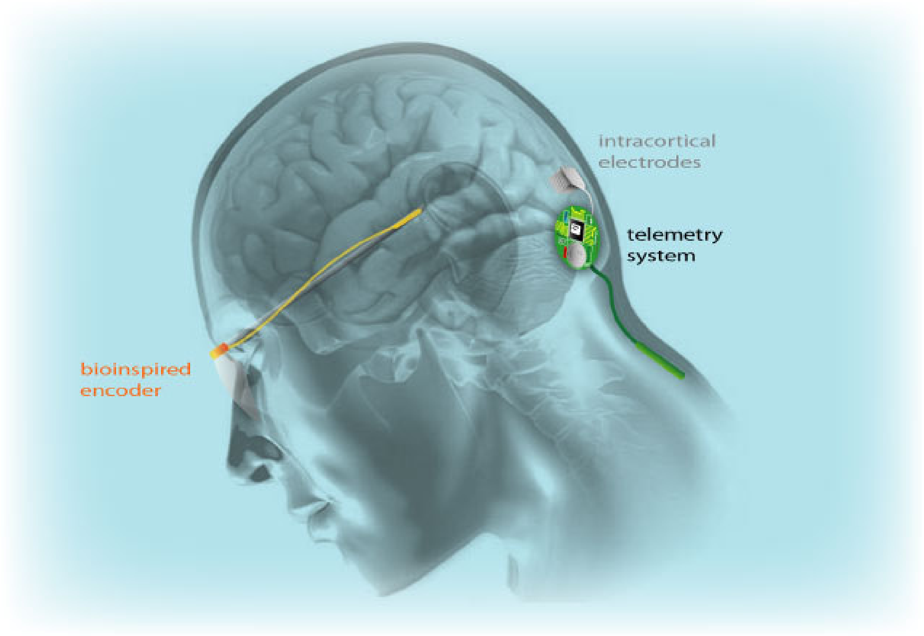


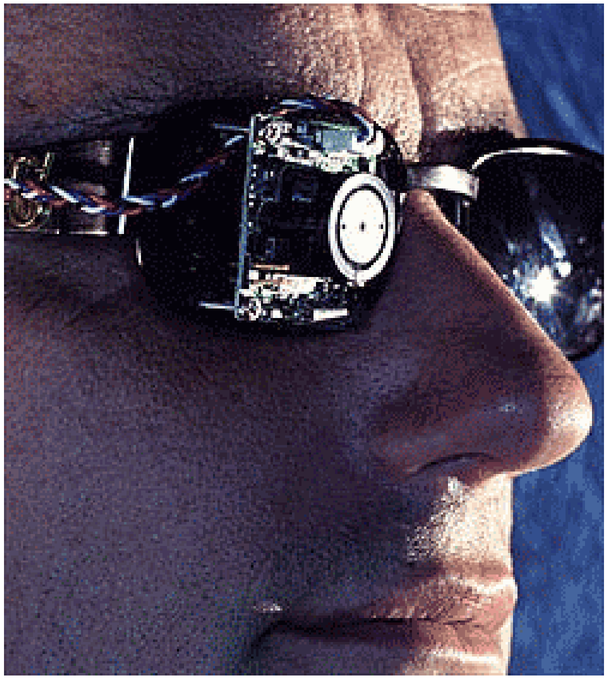


Cochlear implants

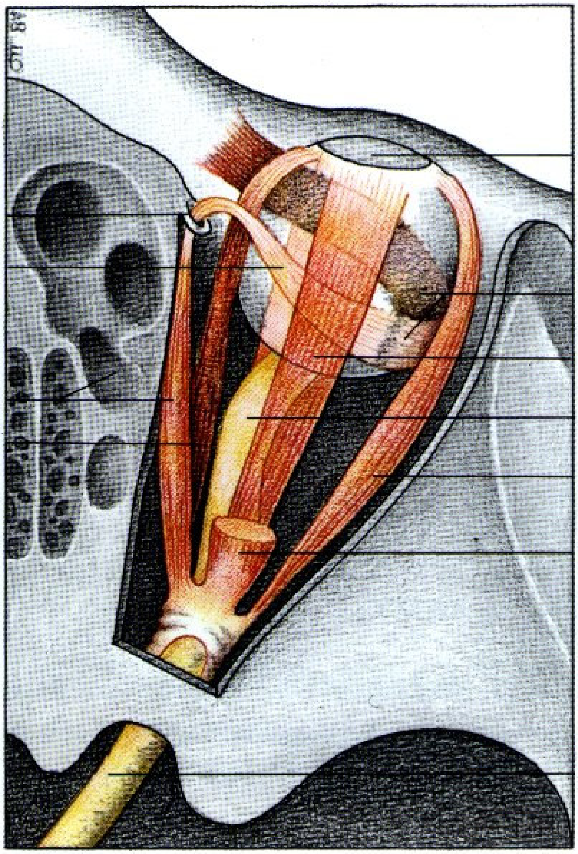
- Up to 22 stimulation electrodes
  - Direct stimulation of auditory nerve fibers
  - Frequency depends on location
  - Normally about 15 000 sensors in ear are used!
- Aimed at restoration of speech recognition
  - Deaf children
  - Adults who lost hearing
  - Requires long-time training !
  - About 59 000 persons received an implant

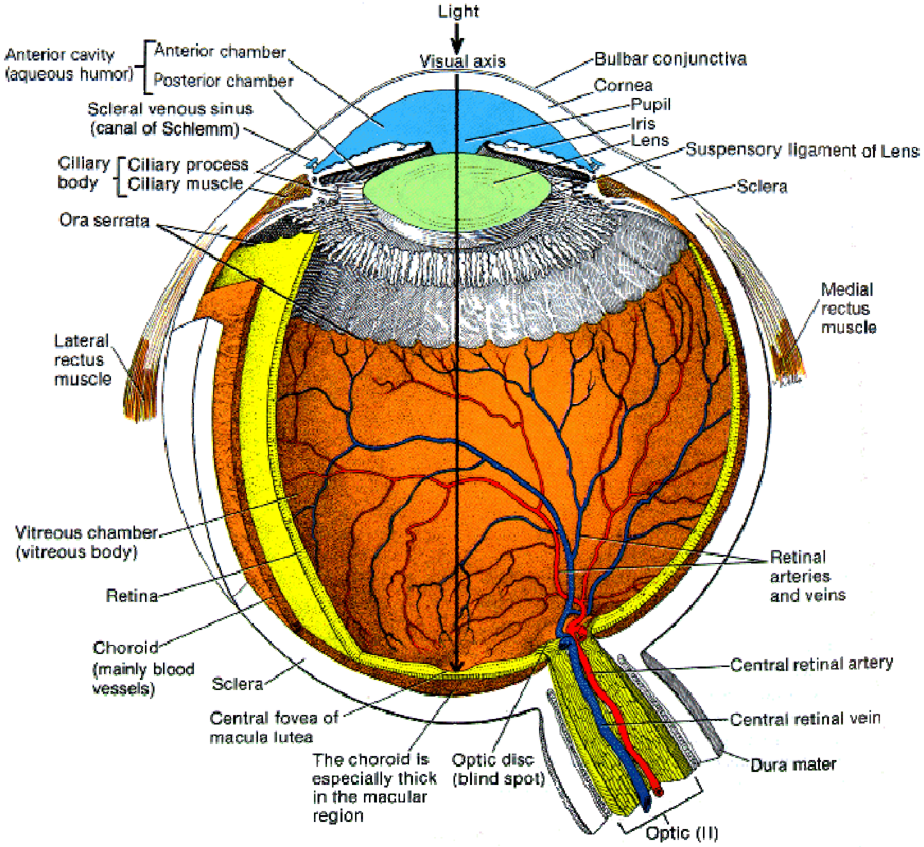
Visual implants Dobelle (1978 – 2004)



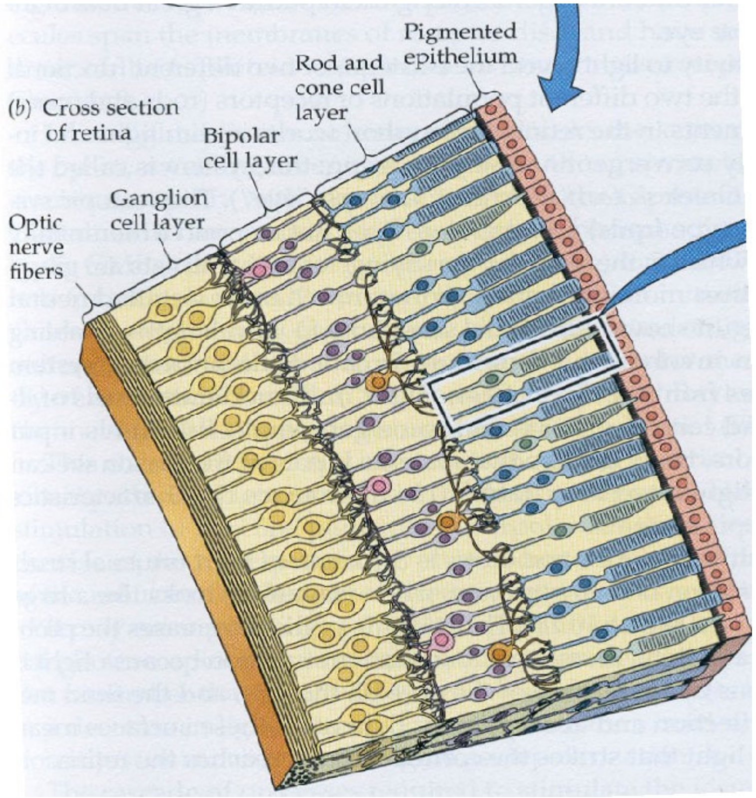


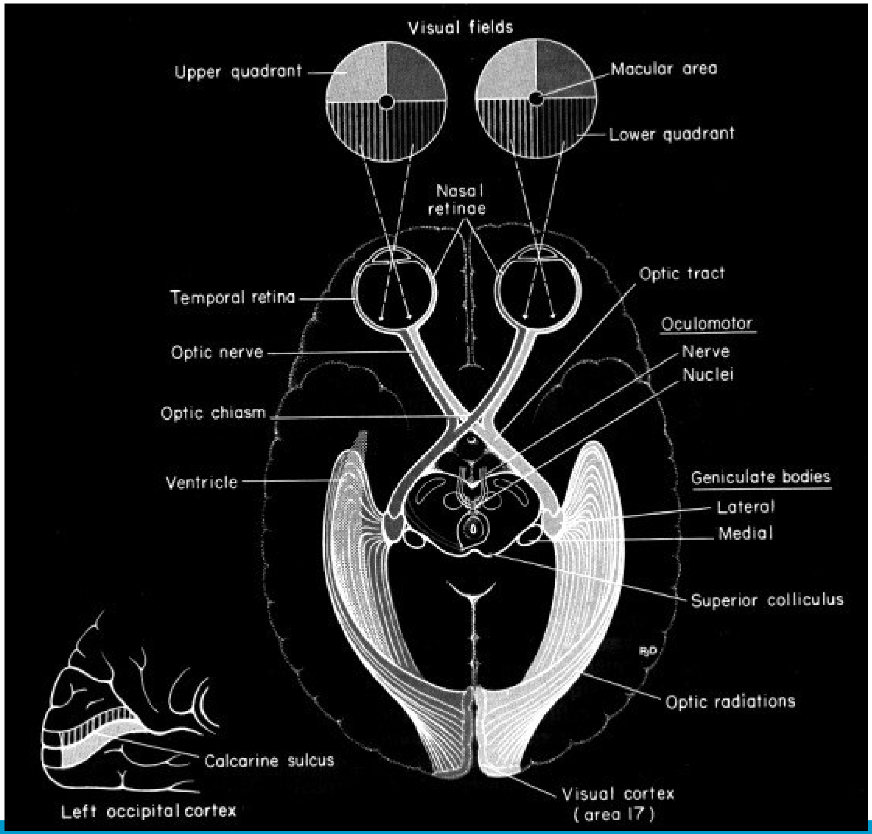
Visual system





Visual cortex





Visual acuity after implant

Driving after implant??

Simulated sight with implant

Visual implants

- Up to 128 electrodes
- Poor encoding possibilities
  - One camera
  - Surpasses primary processing at retina
  - Very complex signal processing at visual cortex
- What will be the limits in resolution?
  - 8 volunteering subjects
  - Extensive training

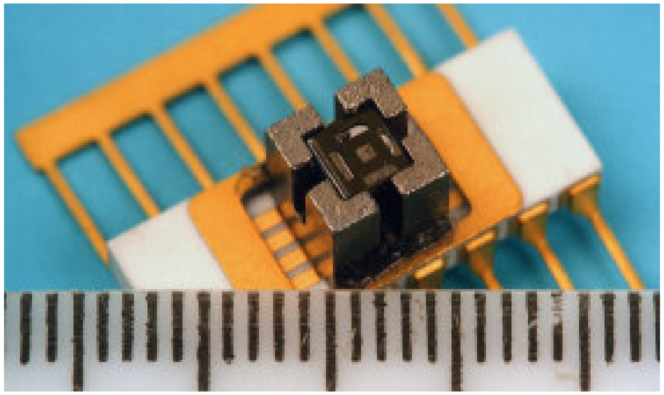
Artificial implantable sensors

- Inertial sensors
- Magnetosensors

Sensing for assistive motor systems

- use body's own sensors and CNS signals
- artificial sensors

Triaxial accelerometer



(Lötters et al., 1998, University of Twente)

Artificial sensors for assistive motor systems

force sensors

- Interface forces:

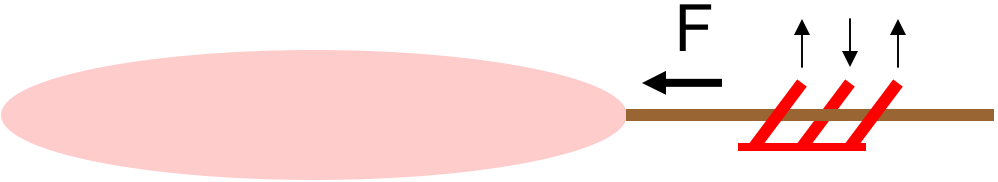
  Force sensitive resistors (FSR)

  Force sensitive capacitors

  Piezo electric also shear forces !

only perpendicular forces

- Tendon force



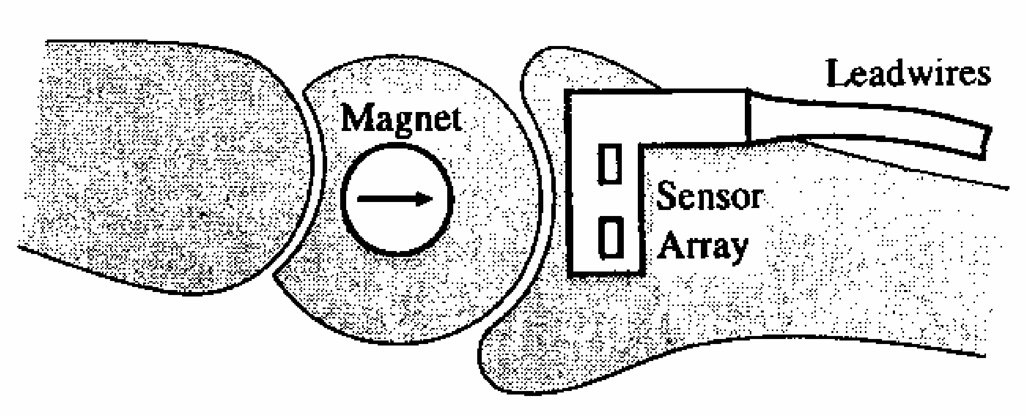
- Bending moments

  E.g. Strain gauges

Artificial sensors for assistive motor systems

movement sensors

- goniometers
- Magnetic sensors



Hall effect based joint angle sensor
(Case Western Reserve University, Cleveland)

- Inertial sensors

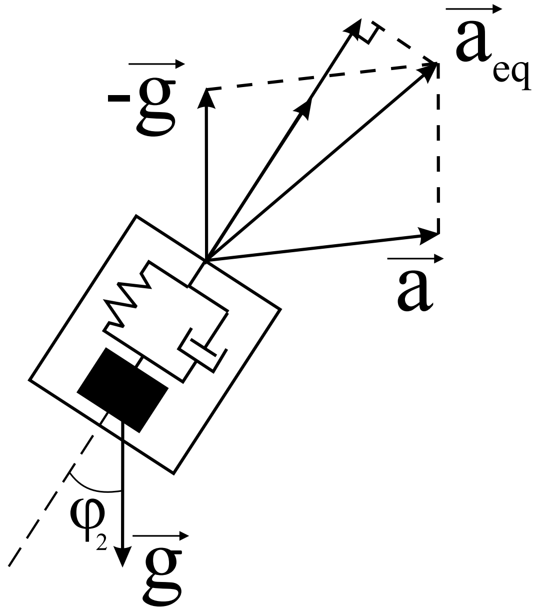
accelerometers

gyroscope

Inertial sensing

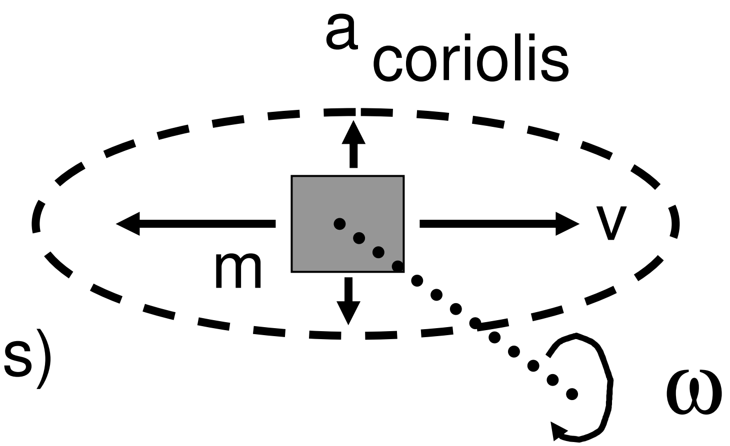
accelerometer

$$\vec{s}_a = \vec{a} - \vec{g}$$

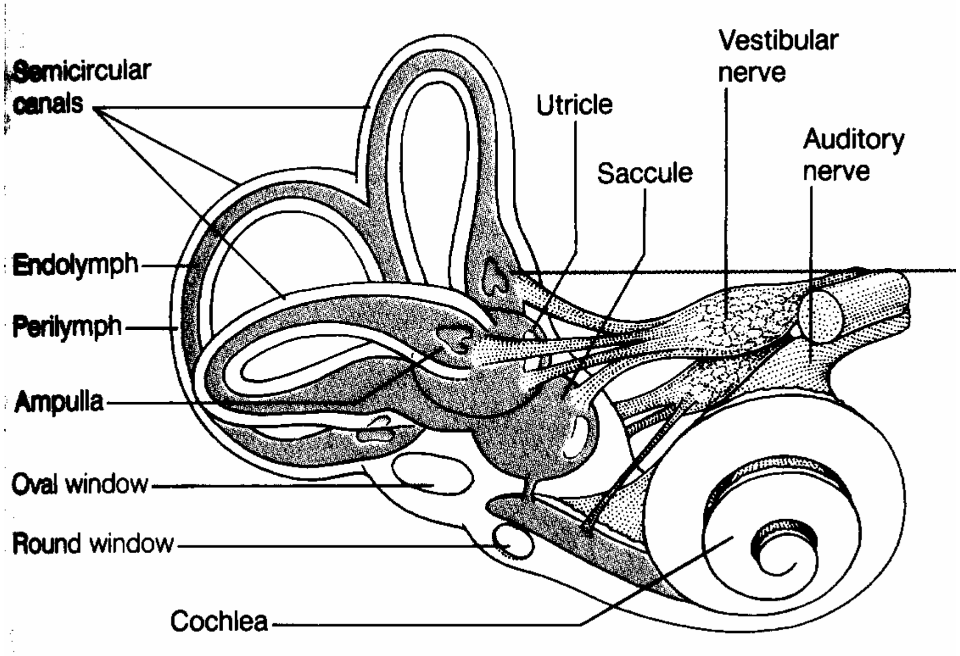


Rate gyroscope
(angular velocity sensor)

$$\vec{F}_C = 2m\vec{\omega}\times\vec{v} \quad \text{(Coriolis)}$$



The human vestibular system
is an 3D inertial sensor system



Inertial sensing

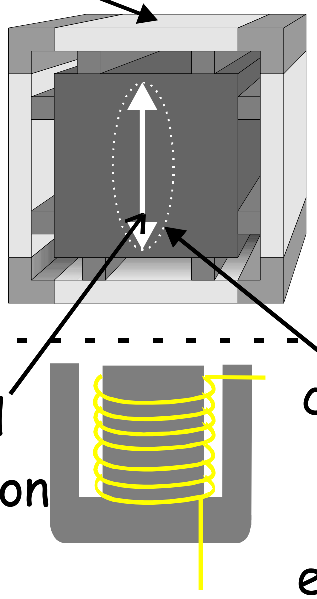
The 3D-movement sensor

sensor

+

actuator

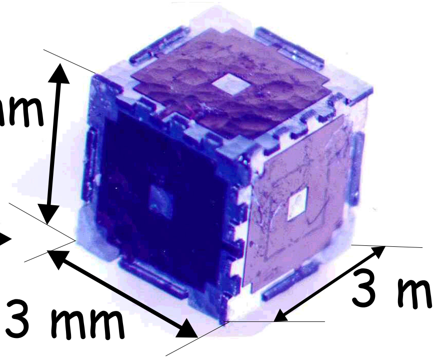
6 silicon sensor plates



applied vibration

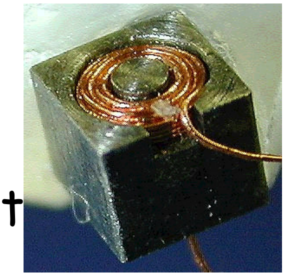
coriolis effect

electromagnet



inertial forces

accelerometer

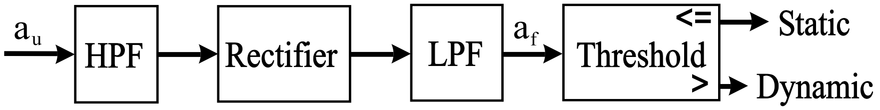


coriolis effect

rate of turn

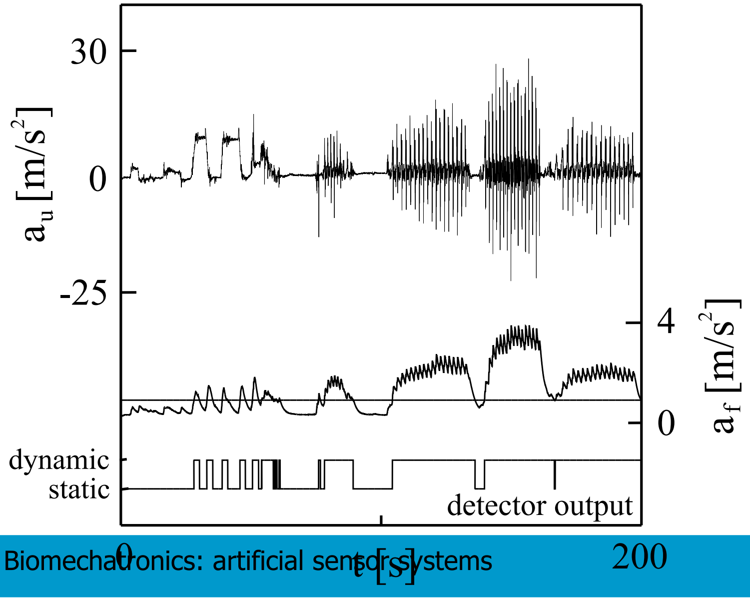
Detection of postures and movements using uni-axial accelerometers

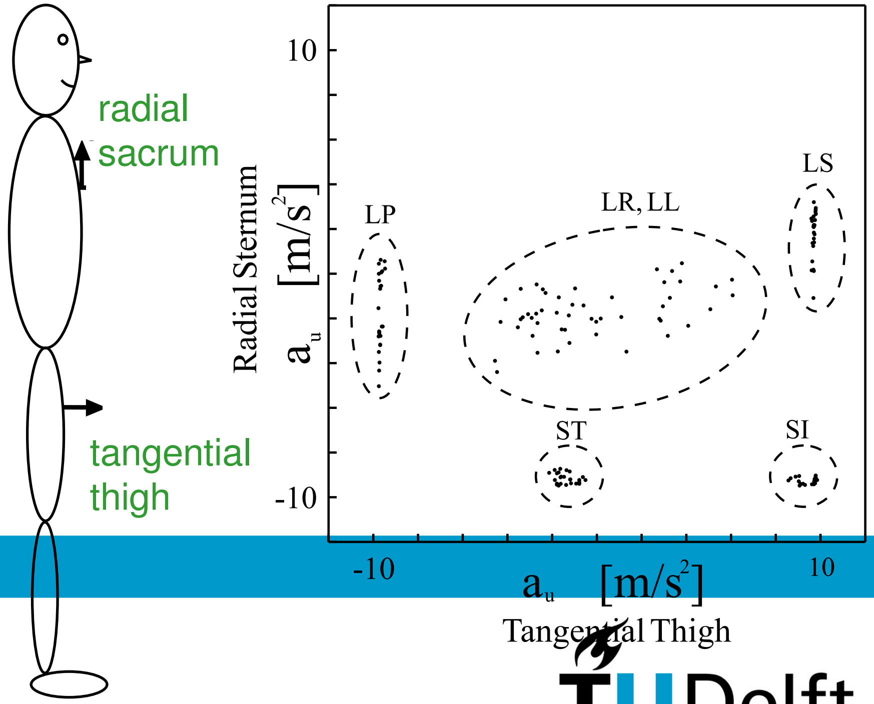
Detector posture - movement



Distinguish postures by analysing inclinations of body segments

Example result detection posture - movement

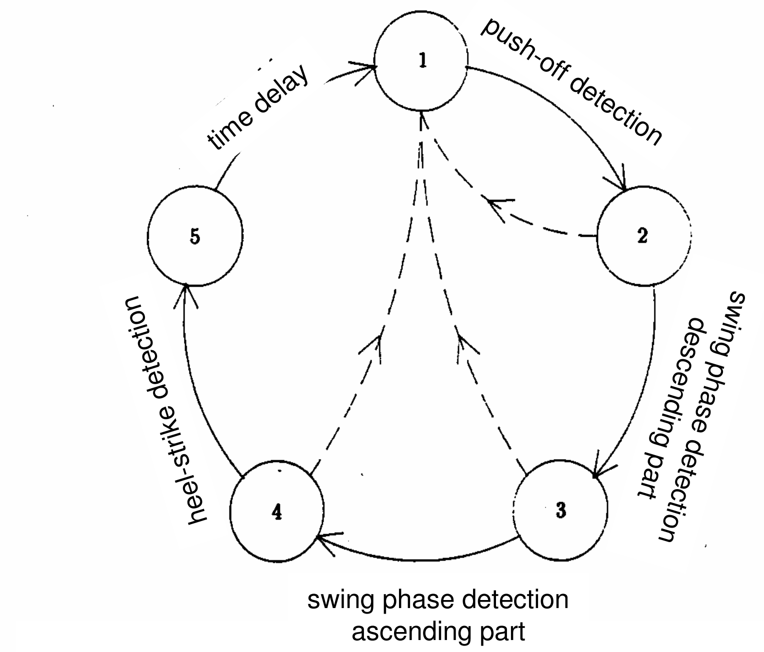


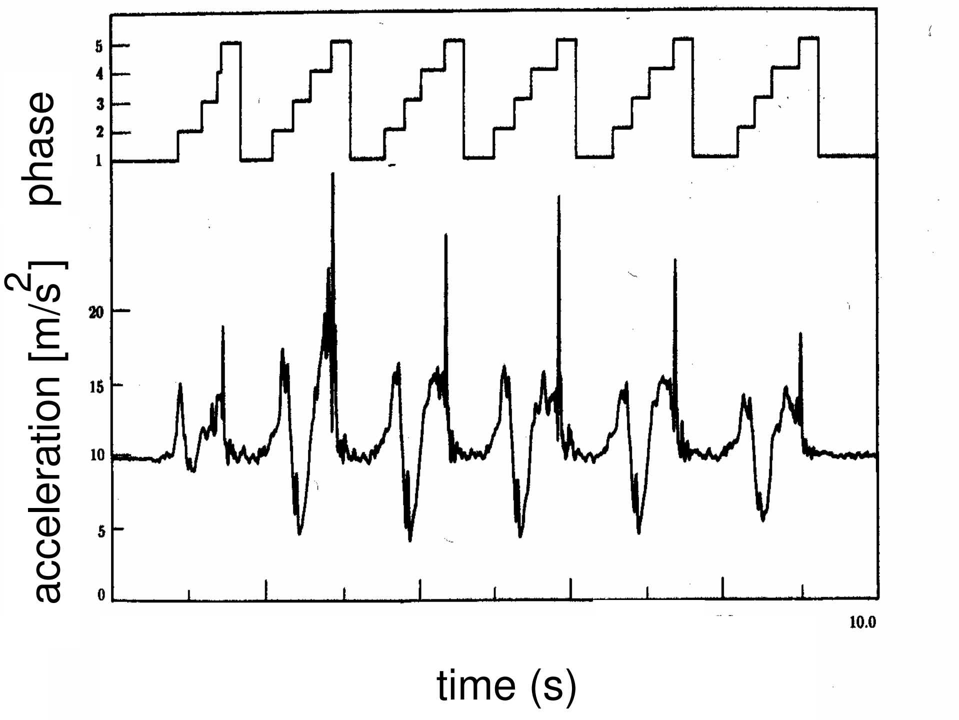


(Veltink et al., 1996)

hemiplegic gait: drop foot stimulator

accelerometer at shank





Willemsen et al., IEEE-BME, 1990

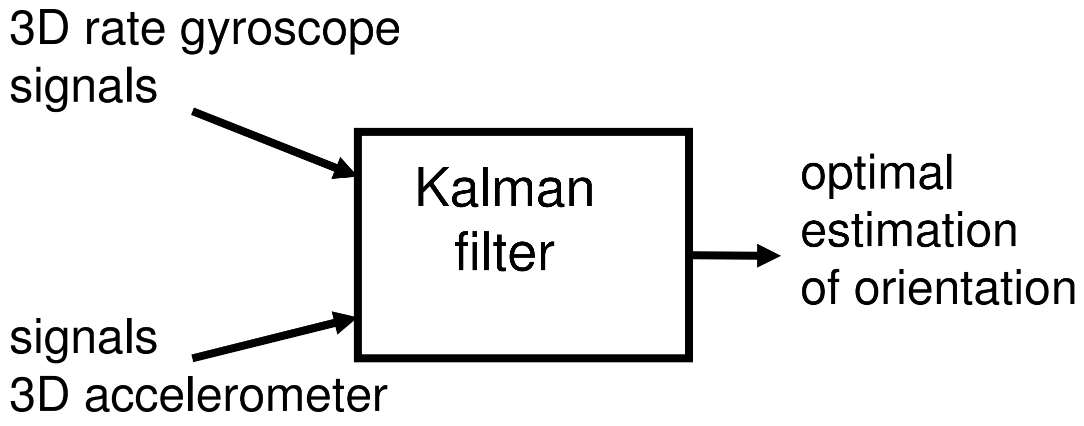
Inertial sensor: quantitative sensing estimation of orientation

signal analysis

$\vec{a}$

$\vec{g}$

$\vec{\omega}$



3D rate gyroscope signals

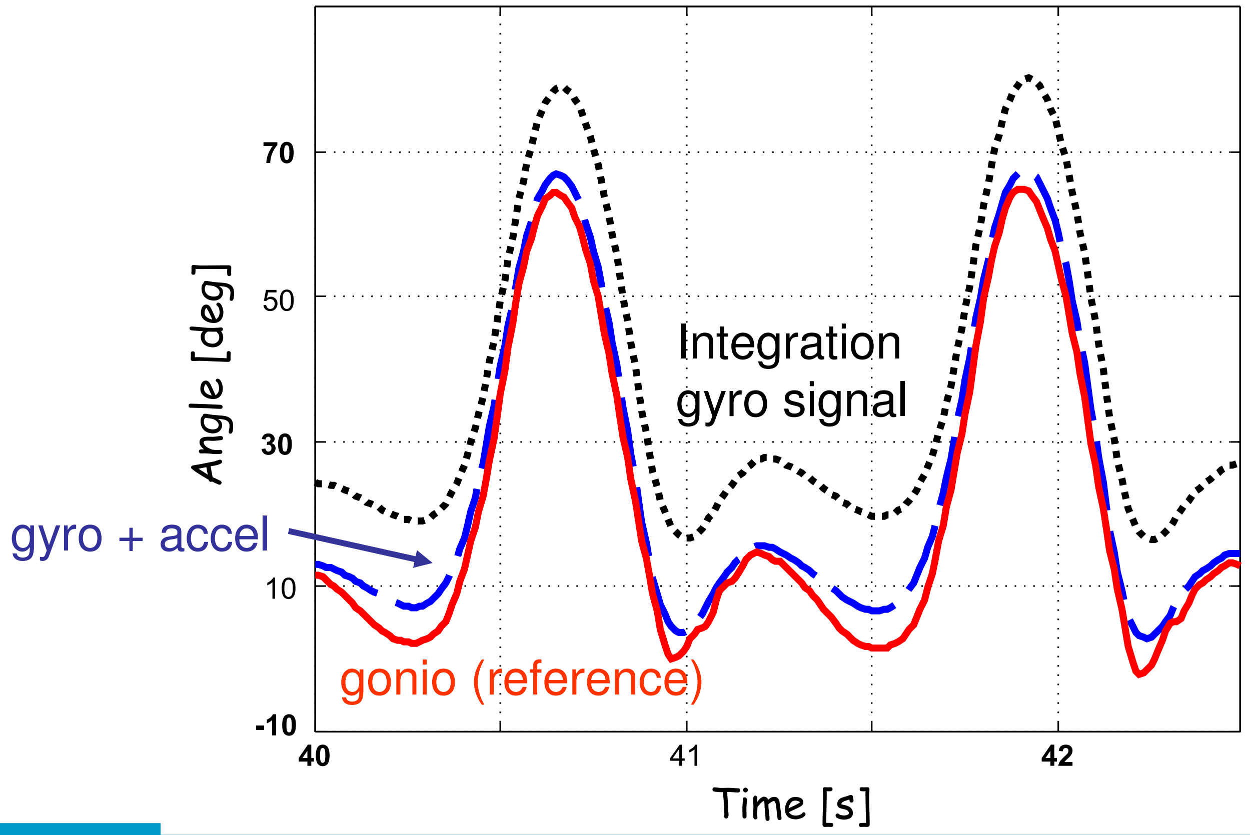
Kalman filter

optimal estimation of orientation

signals 3D accelerometer

(Luinge et al., 1999, University of Twente)

3D inertial sensor system
(accelerometer - rate gyroscope)
reconstruction of knee angle during gait



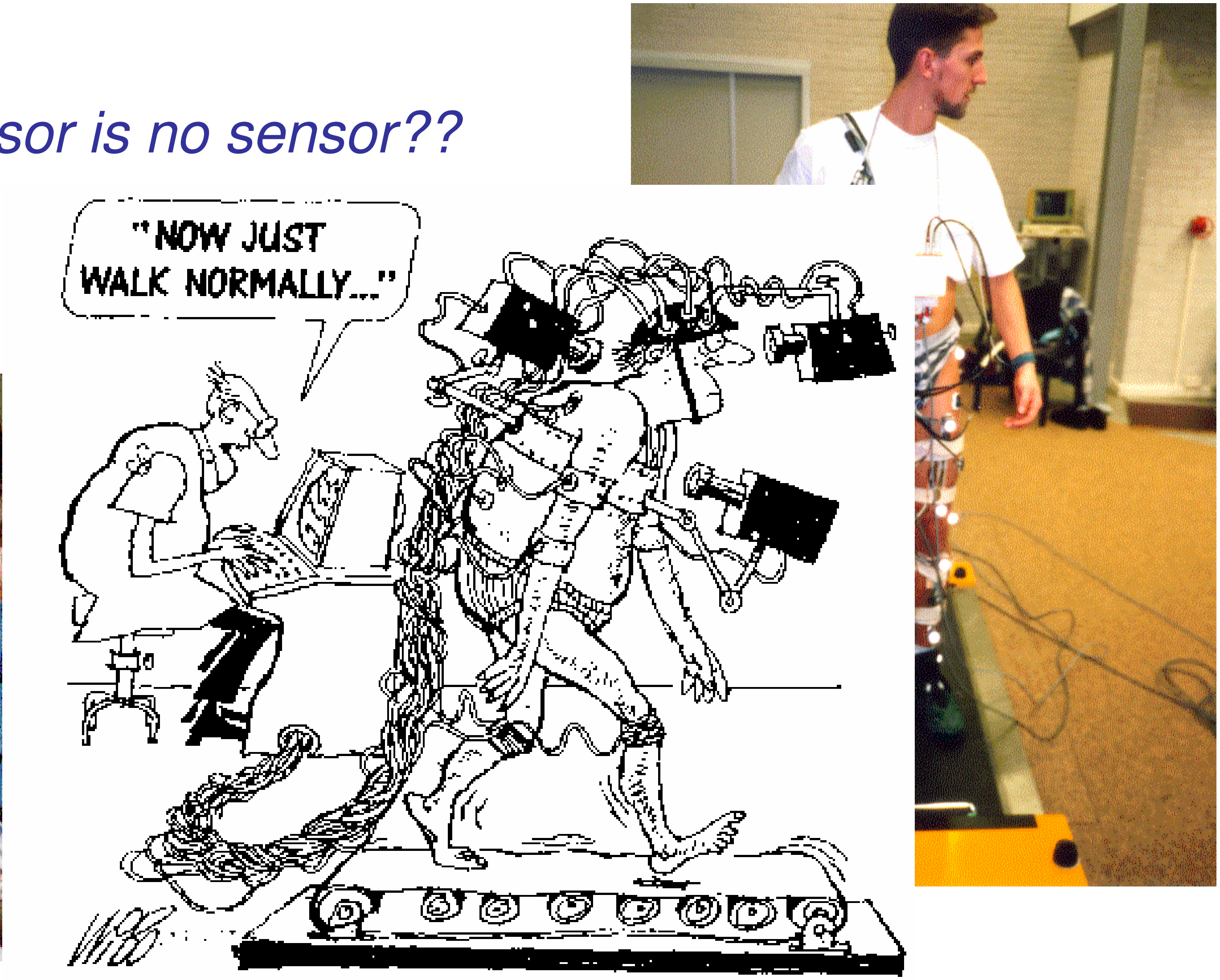
(Luinge et al. 1999)

Reconstruction of knee angle from 3D inertial sensors on thigh and shank

- Sensor axes were directed arbitrarily.
- Initial reference measurement with flexing/extending knee required

Discussion

The best sensor is no sensor??



Discussion

The best sensor is no sensor??

Sensor and control can result in
reproducible, reliable and flexible performance.

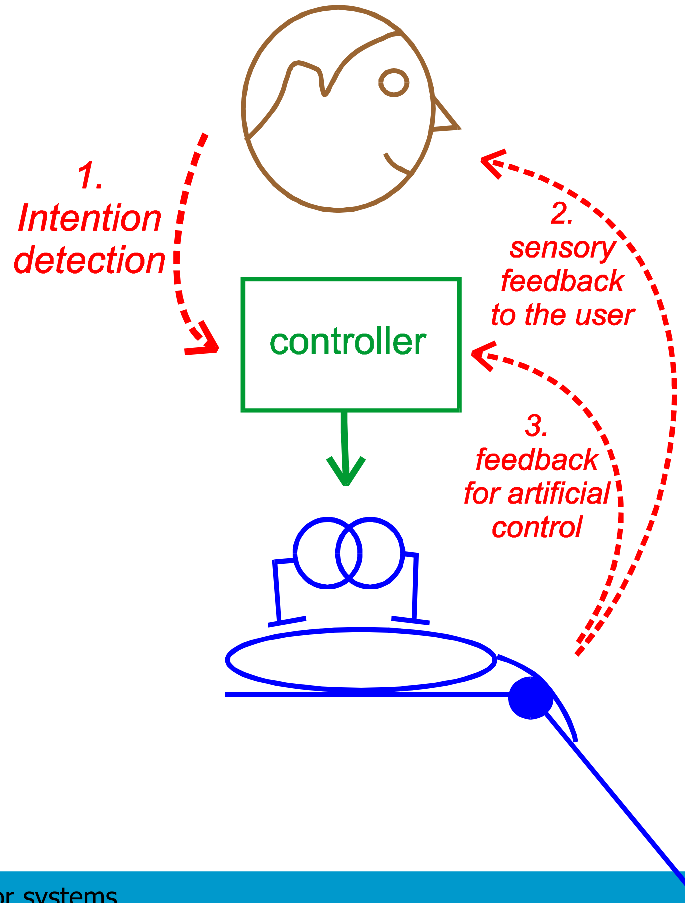
Challenge: the *complexity* of the system
as observed by the user should not increase,
rather decrease!

This is possible:

e.g. - intention detection: no explicit commands
- sensor *in* stimulator or orthotic components
- choose optimal sensors: small, possibly implantable, giving optimal amount of info

Sensing for assistive motor systems

why?



Sensing for assistive motor systems

Sensor	Physical quantity	Transduction principles	Interaction with the body
	CNS signals / muscle activation		
EEG / MEG	*Brain signals*	*Electric / Magnetic*	*Electrodes / coils*
ENG / MNG	*Signals from nerves*	*Electric / Magnetic*	*Electrodes / coils*
EMG / MMG	*Muscle activation*	*Electric / Magnetic*	*Electrodes / coils*

Sensor	Physical quantity	Transduction principles	Interaction with the body
	Force		
Strain gauges	*Strain of material → measure for Force / moment*	*Resistive/ piezoresistive*	*Attachment on prosthetic / orthotic elements*
Pressure sensors	*Pressure*	*- Force Sensitive resistors (FSR)* *- Force Sensitive Capacity*	*Attach between segment and environment on contact surface*
Physiological Skin sensors	*Skin stress (phasic rather than static components)*	*Physiological sensors*	*Derive via electrodes around sensory nerves (Hoffer, Stein et al. 1996; Sinkjaer 1999)*

Sensing for assistive motor systems

Sensor	Physical quantity	Transduction principles	Interaction with the body
	Movement		
Goniometer	*Joint angle (1, 2 or 3D)*	*- Resistive* *- Hall effect + magnet (Johnson, Peckham et al. 1999)*	*Attach to two segments connected by joint*
Orientation sensor	*Orientation with respect to earth coordinate system*	*- Hall effect (earth magnetic field)* *- inertial: gravity acceleration*	*Attach sensor to body segment*
Rate of turn Gyroscope	*Angular velocity (1 – 3D)*	*- inertial, coriolis / piezoresistive (Soderkvist 1994)*	*Attach to body segment (Baten, Oosterhoff et al. 1996)*
Accelerometer	*Acceleration (inertial + gravitational: 1 – 3D)*	*Inertial / piezoresistive, piezoelectric or capacitive (Lotters, Olthuis et al. 1995)*	*Attach to body segment*
Position sensor	*- relative distance to objects in environment* *- absolute position in space*	*- radar using ultrasonic transmitters/sensors (Piezo electric)* *- GPS: Global Positioning System using satellite communication*	*-ultrasonic transmitters / senors mounted on body (Shoval, Borenstein et al. 1998)* *- GPS system mounted on body*