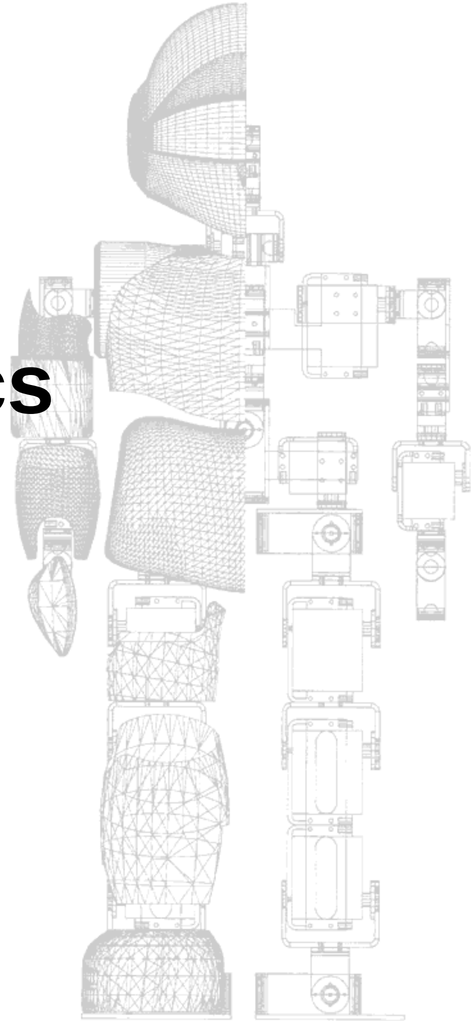
wb2432
Rehabilitation Robotics



Dick Plettenburg
Richard van der Linde

3mE, BMechE

This lecture

CONTENT

- Introduction & definitions
- Robot control schemes

Part 1

- Identification & diagnostics robots
- Therapy robots
- Assistive robots
- Prosthetics
- The future of rehabilitation robots

Part 2

- Video: ARM

Part 3

Introduction & definitions

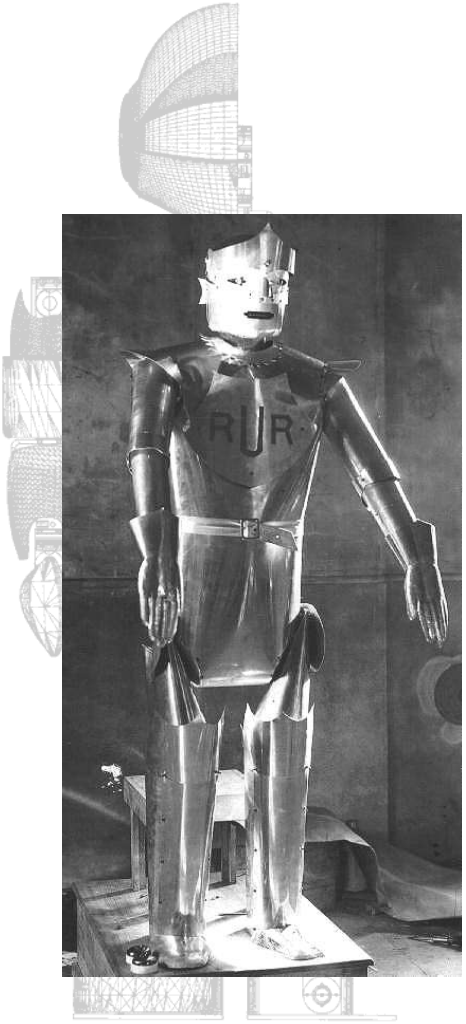
Definition of the word *robot*

robota [Czech], play of Karel Capec 1921

means ‘work‘, or ‘forced workers’, or ‘slaves’

Dictionary:

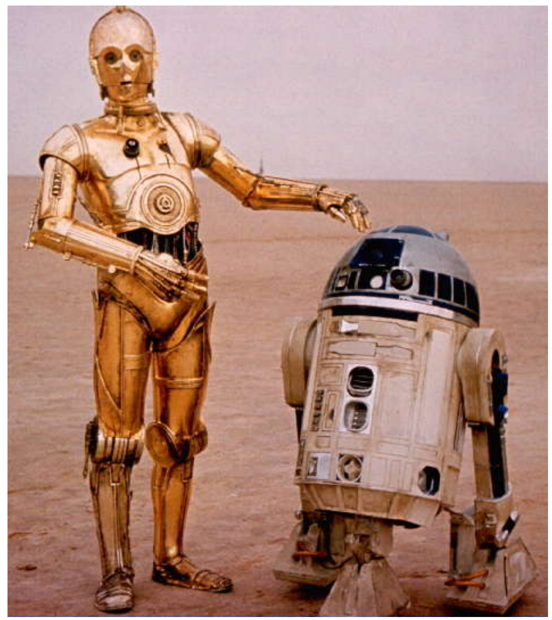
1. A mechanical device that sometimes resembles a human being and is capable of performing a variety of often complex human tasks on command or by being programmed in advance.
2. A machine or device that operates automatically or by remote control.
3. A person who works mechanically without original thought, especially one who responds automatically to the commands of others.



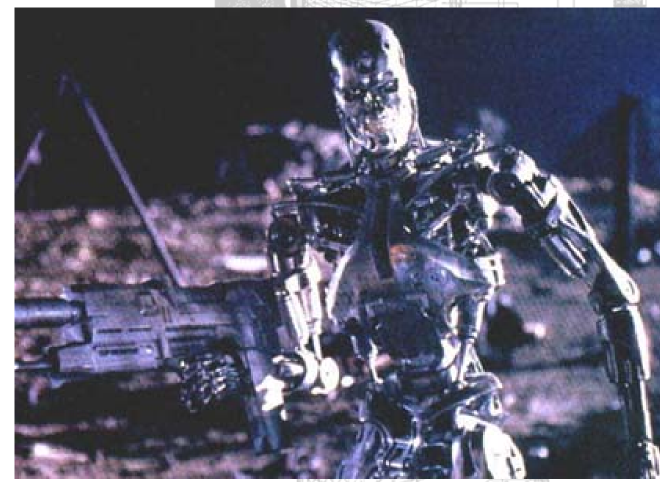
Introduction & definitions

Fiction robots

1956, Forbidden Planet



1977, Star Wars



1999, Terminator

Introduction & definitions

1961, first "real" robot

The first industrial robot, called Unimate, GM factory in New Jersey

1970-1999 over 1.100.000 industrial robots installed

NO human interaction !!!

Introduction & definitions

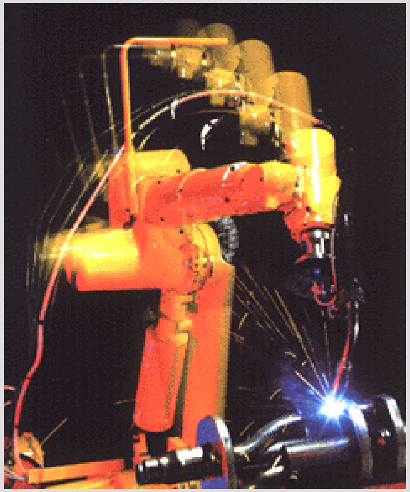
first step

robots

service robots

- adaptation
- autonomy
- safety

manufacturing robots



- speed
- accuracy
- payload
- reliability

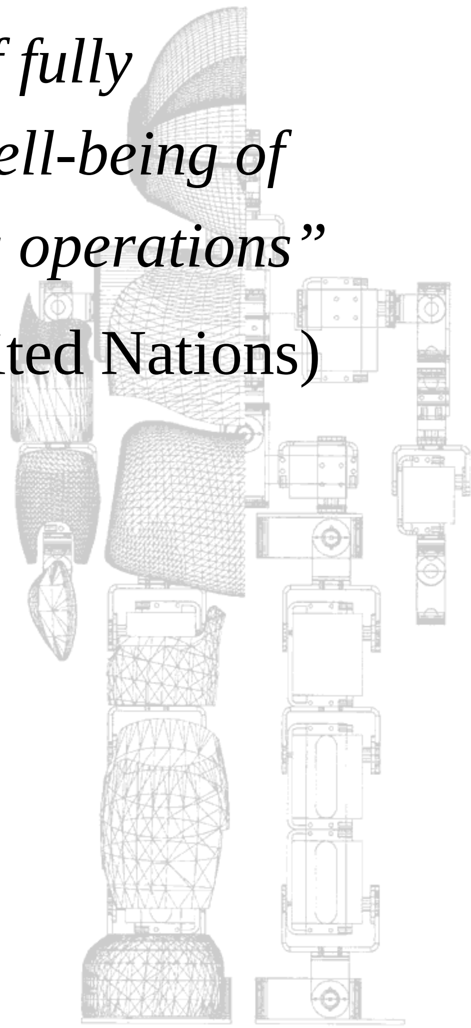
Introduction & definitions

*"**Service robots** are robots which operate semi of fully autonomously to perform services useful to the well-being of humans and equipment, excluding manufacturing operations"*

(World Robotics 2000, The Int. Fed. of Rob., United Nations)

example application areas:

- cleaning robots (tank, floor, window, pipes, etc.)
- inspection robots (power plants, nuclear, etc.)
- domestic robots (vacuum, lawn, etc.)
- medical robots (surgical assistance, equipment holder)
- assistive robots (for disabled persons)
- entertainment

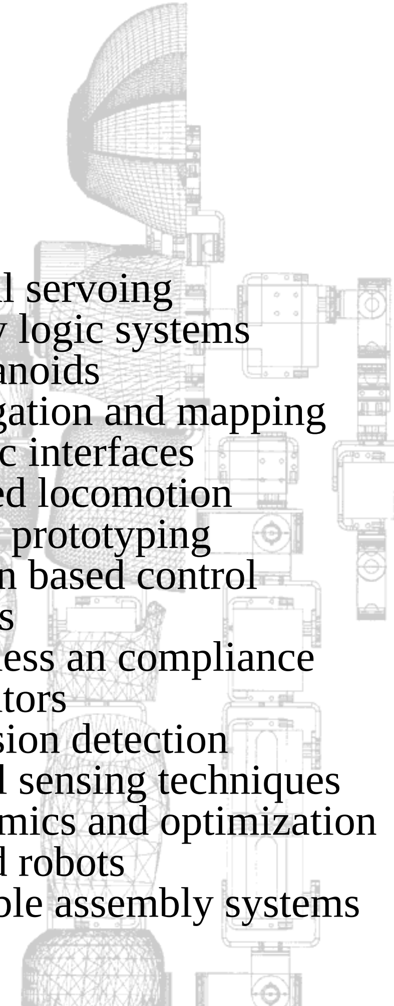


Introduction & definitions

Robotics covers an extensive field of research

(sessions on ICRA 2000, San Francisco, USA)

- path planning
- mapping and localization
- grasping and manipulation
- kinematics
- mechanisms
- architectures
- micro robots
- manufacturing system design
- space robots and rovers
- autonomous robots
- space and underwater robots
- range sensing
- part feeding and fixing
- rehabilitation robots
- assembly and motion planning
- environmental modeling
- flexible robots
- robot control
- dexterous manipulation
- robot learning
- novel transmission methods
- surgical robots
- target tracking
- redundant manipulators
- mobile robotics
- reconfigurable robots
- nonholonomic motion planning
- neural network systems
- cooperative robots
- mechatronics
- parallel manipulators
- tele-operation
- visual servoing
- fuzzy logic systems
- humanoids
- navigation and mapping
- haptic interfaces
- legged locomotion
- rapid prototyping
- vision based control
- mems
- stiffness an compliance
- actuators
- collision detection
- novel sensing techniques
- dynamics and optimization
- biped robots
- flexible assembly systems



Introduction & definitions

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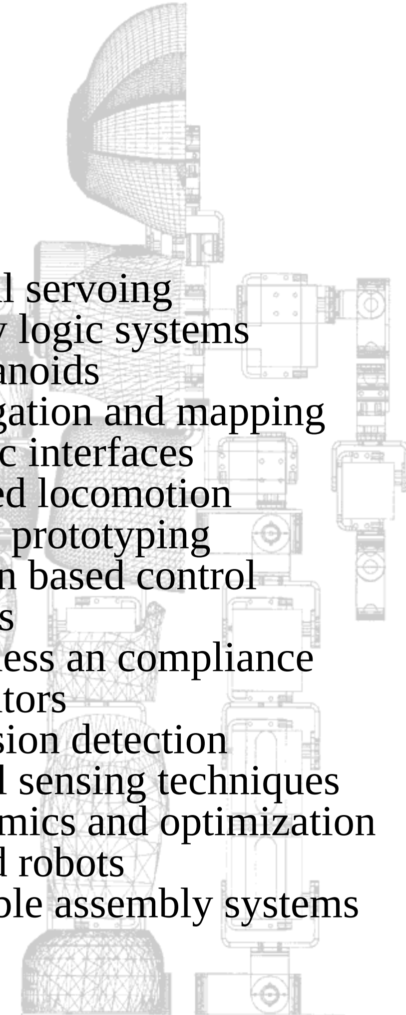


Extended into 168 sessions at ICRA 2007, Roma, Italy

Introduction & definitions

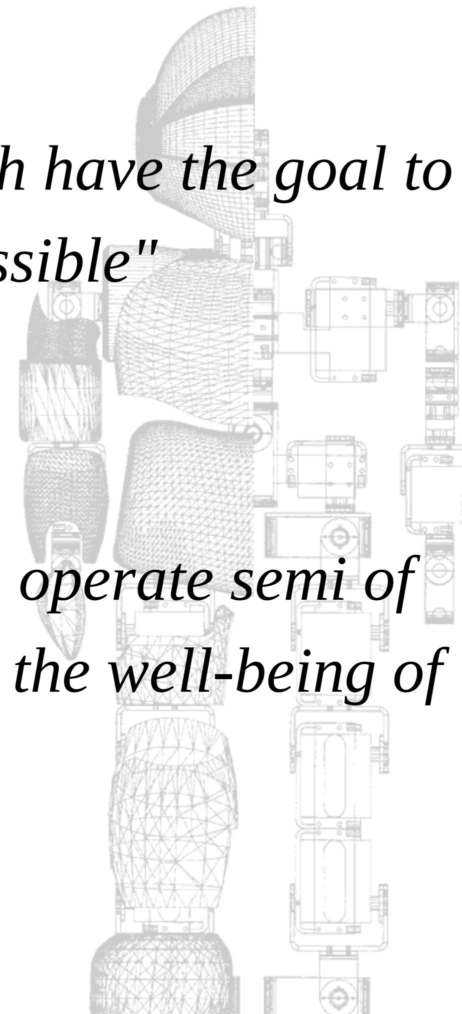
Definition of the word *rehabilitation*

"The entirety of medical and social means, which have the goal to restore the functions of the patients as far as possible"

(Dikke Van Dale)

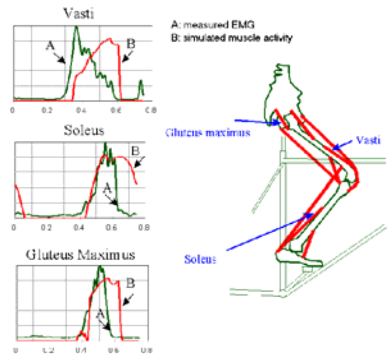
*"**Rehabilitation robots** are service robots which operate semi of fully autonomously to perform services useful to the well-being of disabled humans"*

(R.Q. van der Linde, 2003)

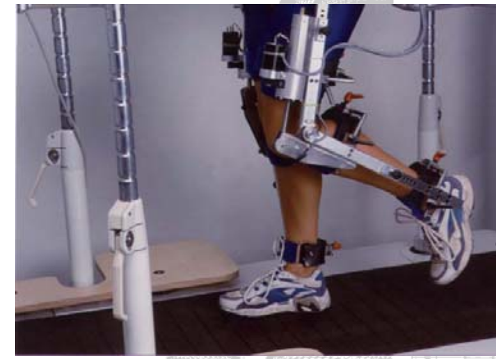


Introduction & definitions

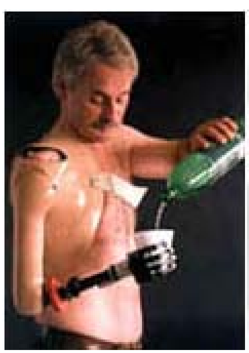
4 functional areas of rehabilitation robots:

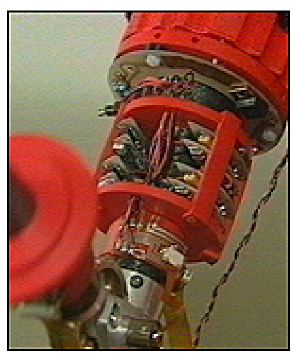


identification & diagnostics



therapy assistance



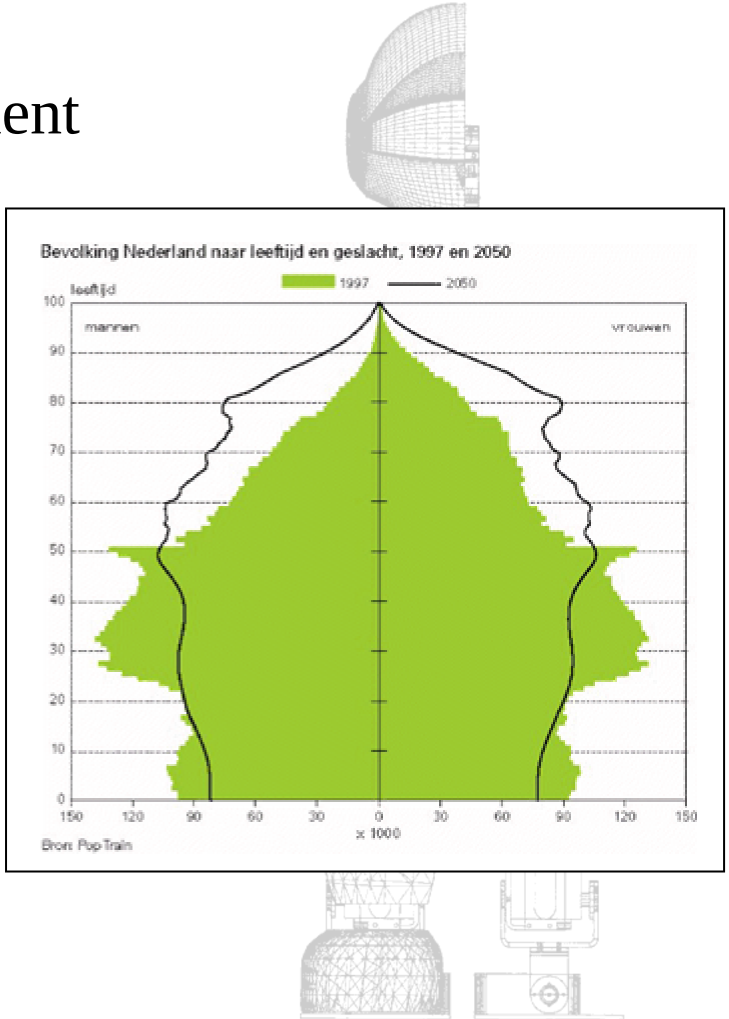


prosthetics

living assistance

Why rehabilitation robots ?

- We have an increasing need for treatment
  - more elderly people
  - more diseases
- Robot therapy might be effective
  - motivating
  - accurate
  - objective
  - adaptive
- Robot therapy enables home care



Why NOT rehabilitation robots ?

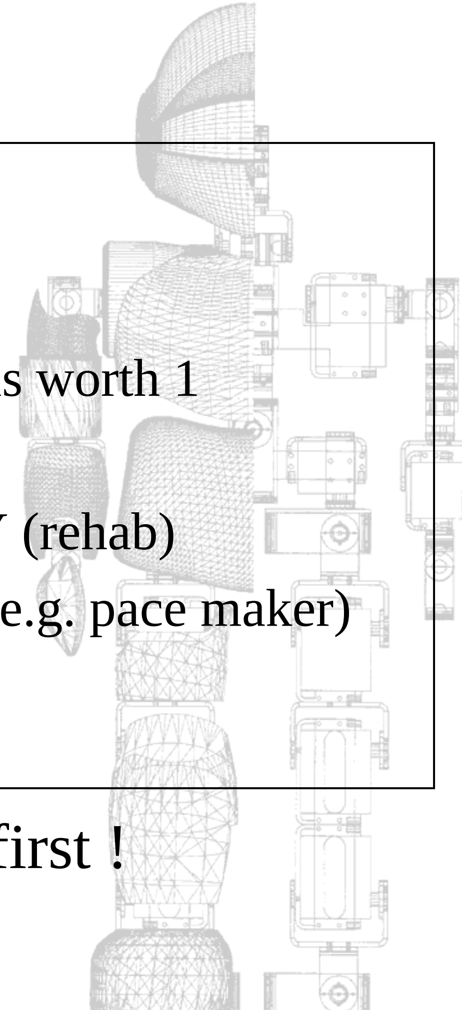
- Because the QALY factor is low

QALY (Quality Adjusted Life Year)

goal:	to measure the value quality of life
definition:	1 year of perfect health-life expectancy is worth 1
	QALY = quality of life
examples:	- 4 year life extension * 0.1 = 0.4 QALY (rehab)
	- 2 year life extension * 1 = 2 QALY (e.g. pace maker)

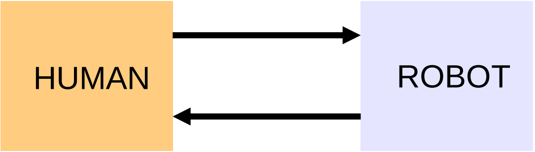
NL: QALY = 25.000 Euro

- Because proven therapy results are required first !
- Because it is complex



Technical issues

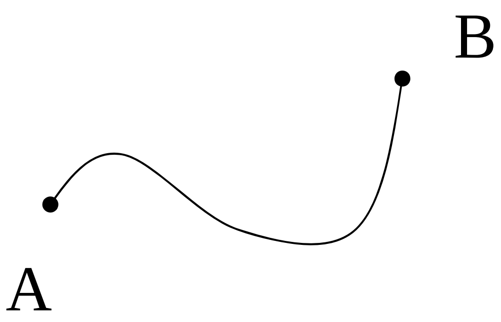
Interaction between (disabled) human operator and robot



- what type of motion control is required ?
- how to interface with the robot ?
- reliability
- safety

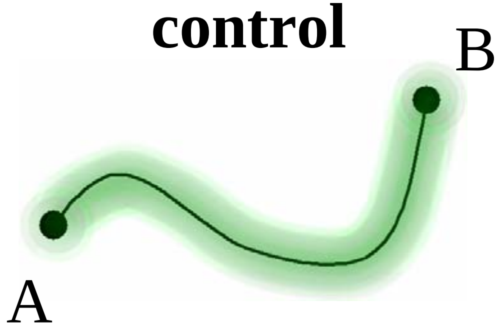
Types of movement control

position control



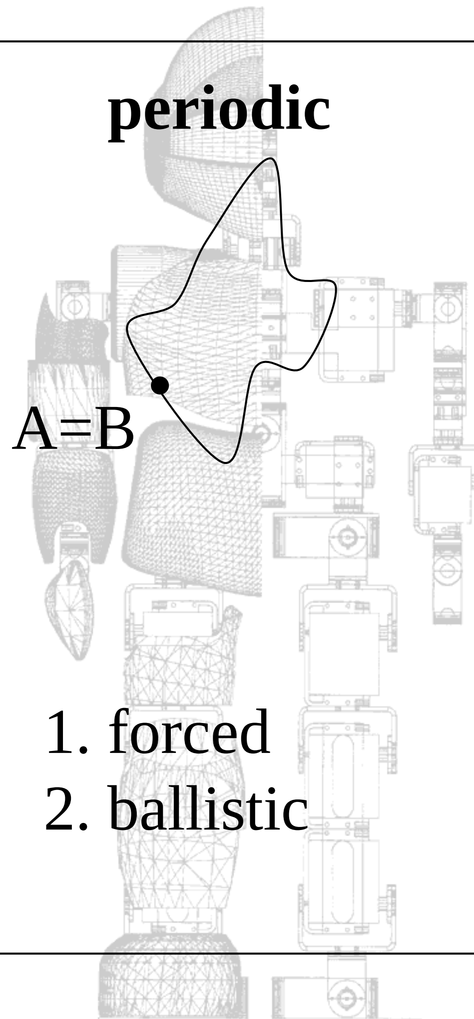
1. position control
2. force control

force/position control



1. impedance
2. admittance
3. intrinsic

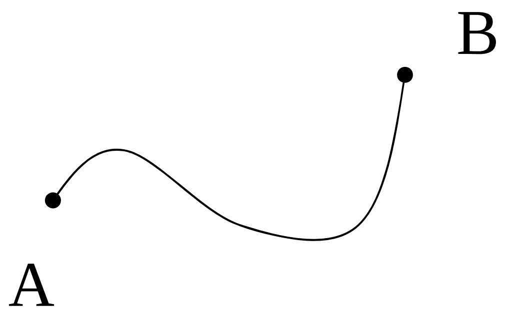
periodic

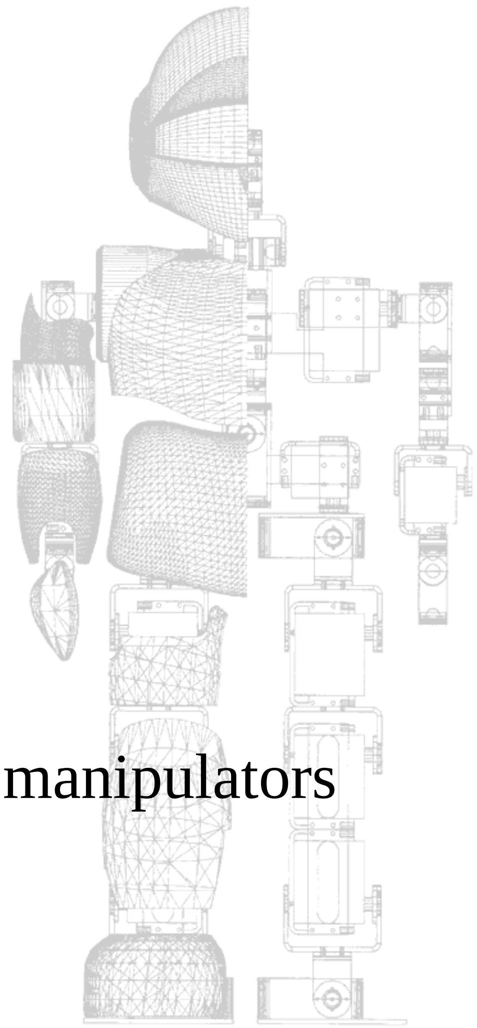


1. forced
2. ballistic

Types of movement control

position control



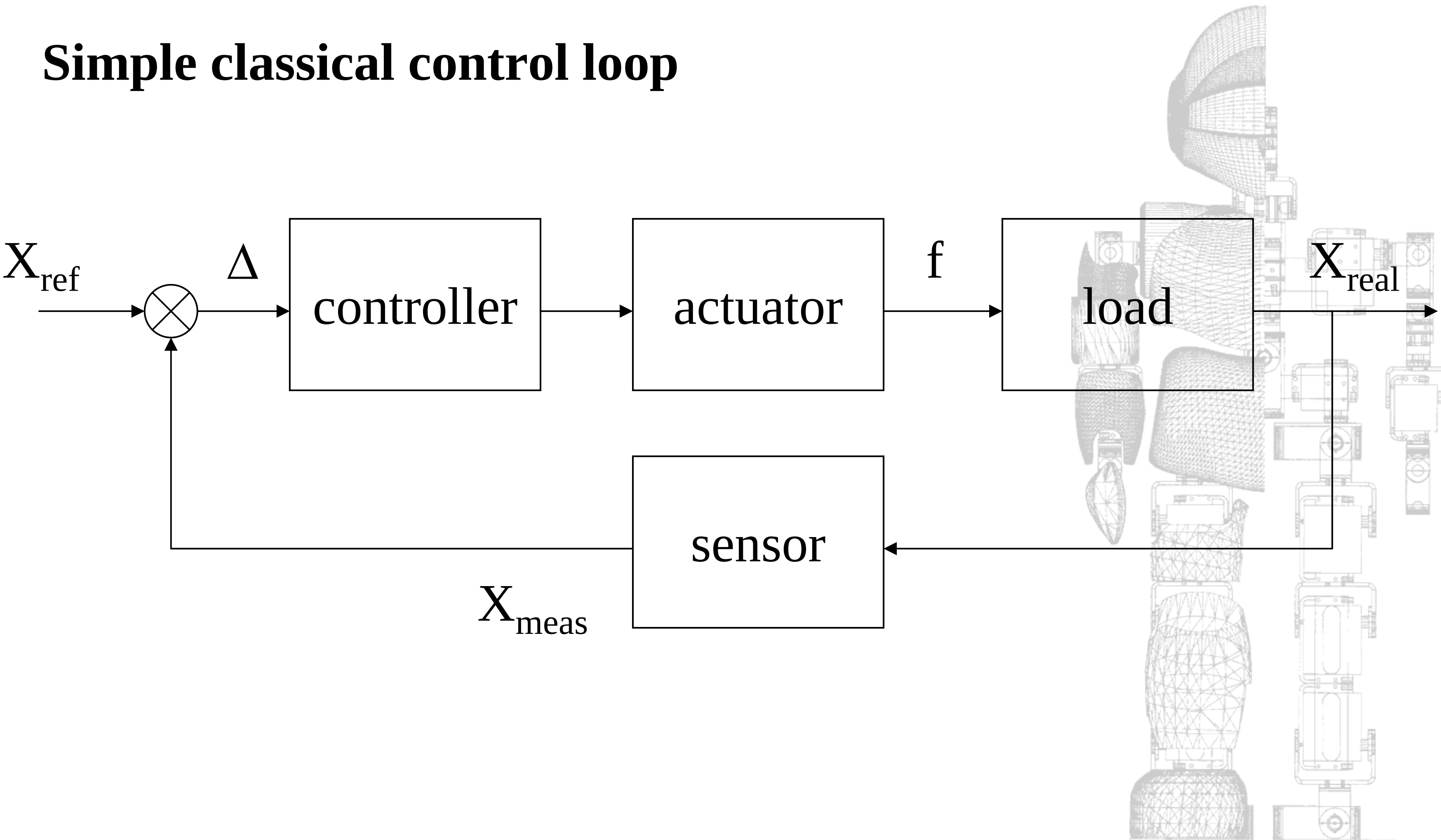


When ?

•prescribed displacement, e.g. movement of manipulators
•prescribed force, e.g. pinching

Position control

Simple classical control loop



Position control

Example: simplest control loop

suppose 2nd order load

$$m\ddot{x} = f - \kappa\dot{x} - cx$$

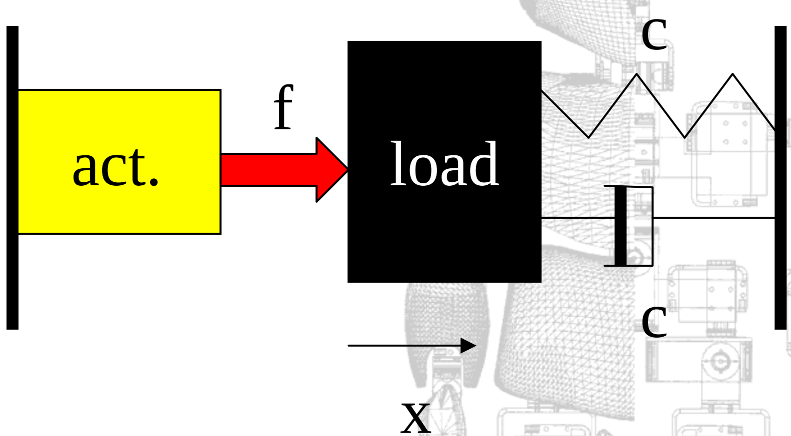
rewriting

$$\frac{x}{f} = \frac{1}{ms^2 + \kappa s + c}$$

or

$$\frac{x}{f} = \frac{1/c}{\frac{s^2}{\omega_0^2} + 2\beta\frac{s}{\omega_0} + 1}$$

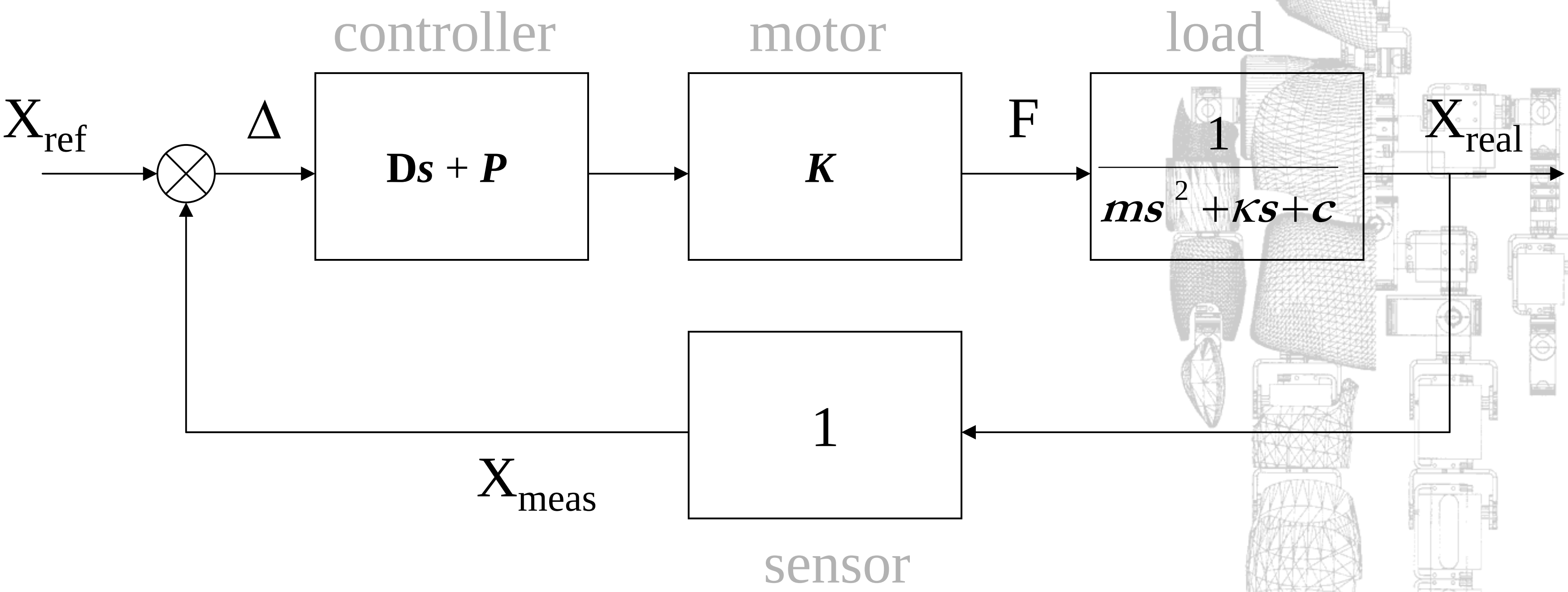
$$\omega_0 = \sqrt{\frac{c}{m}}$$



x=displacement
f=force
c=stiffness
κ=damping

Position control

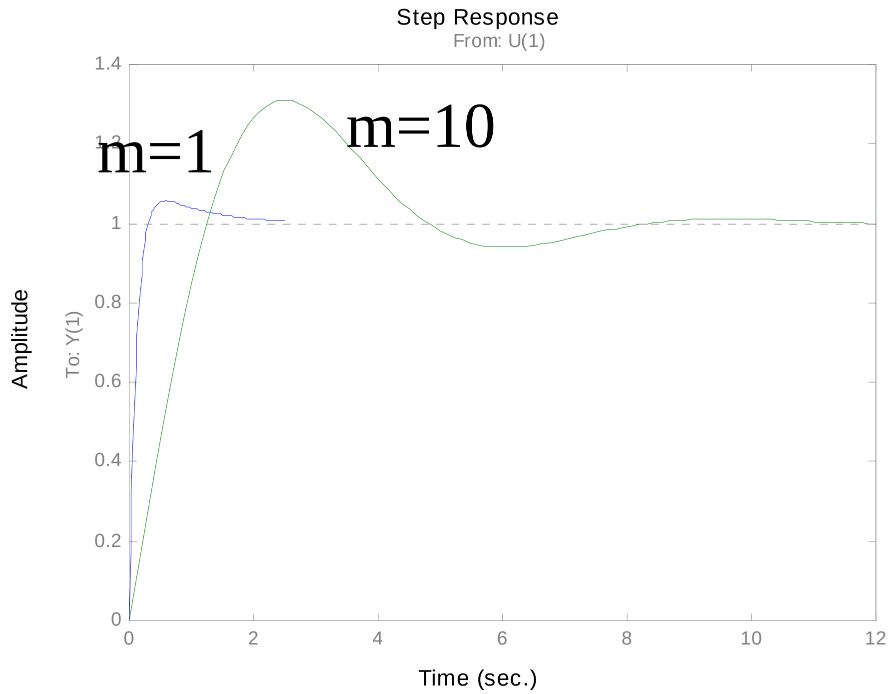
Example: simplest control loop, block scheme



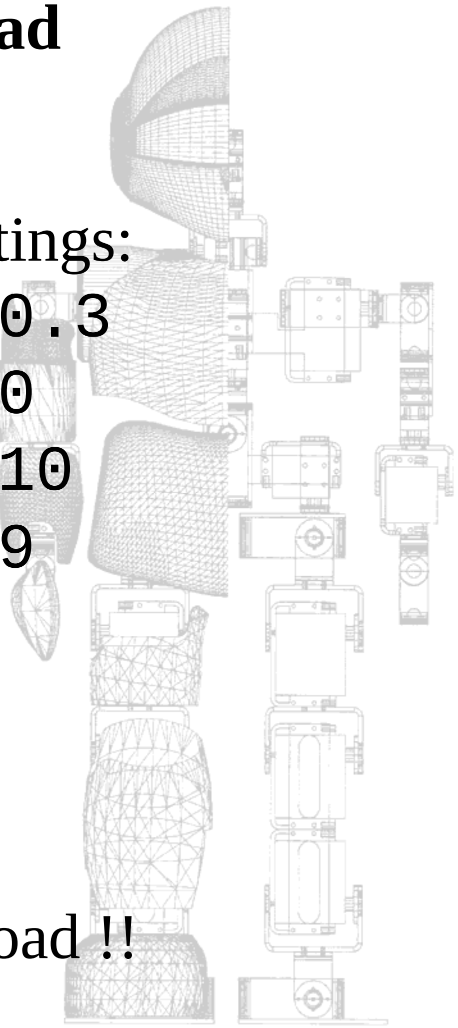
- ideal sensors
- ideal motor

Position control

Example : simplest control loop, high & low load



settings:
b=0.3
c=0
P=10
D=9

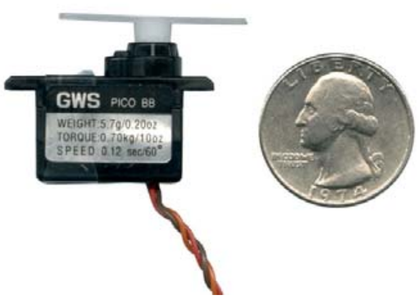


Conclusion:

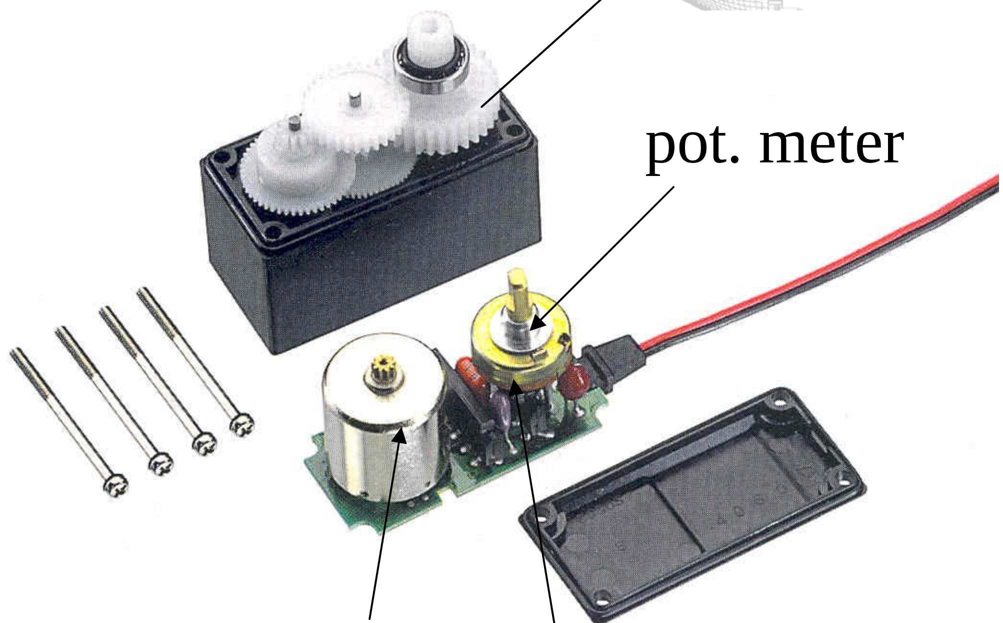
Safe & optimal control loop settings depend on load !!

Position control

Commercial products: hobby servo

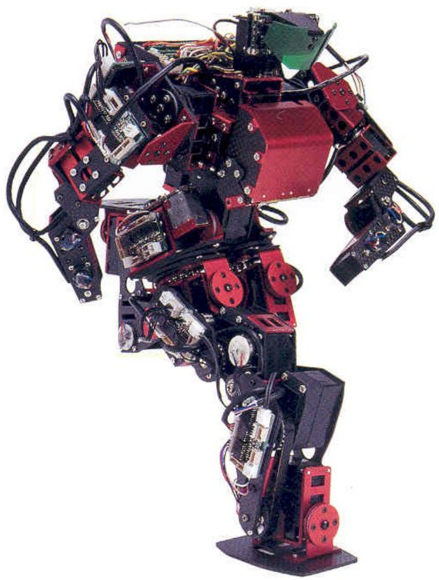


miniature

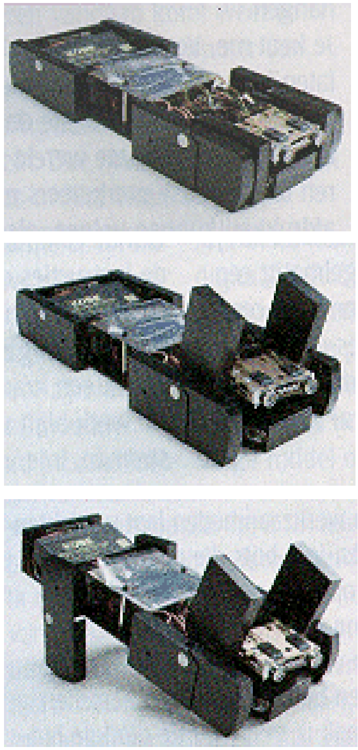


Position control

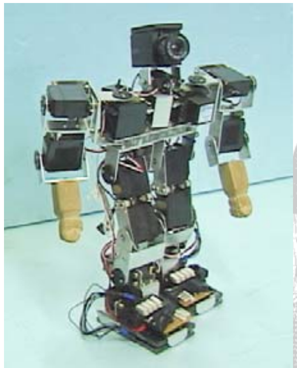
Example projects with hobby servos

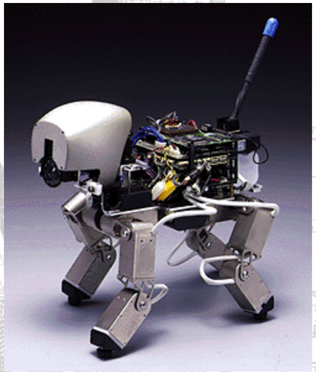


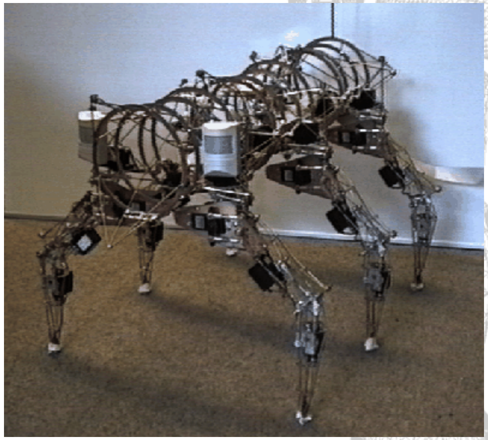
Morph



Dappie

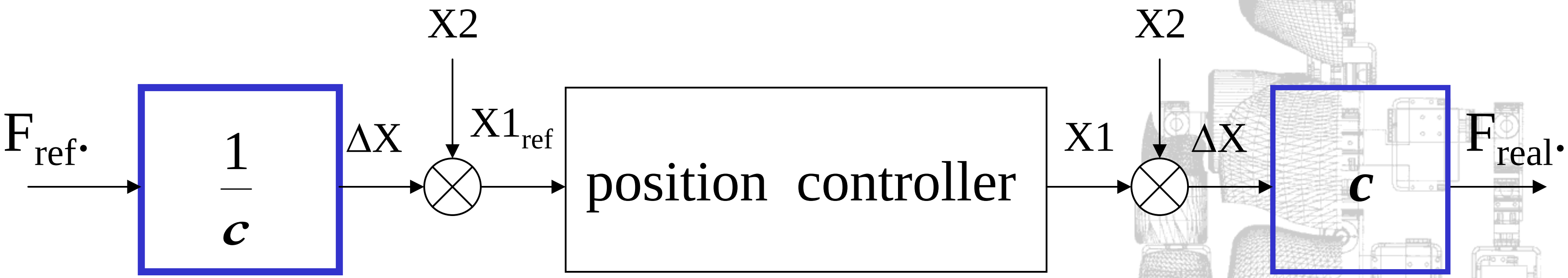


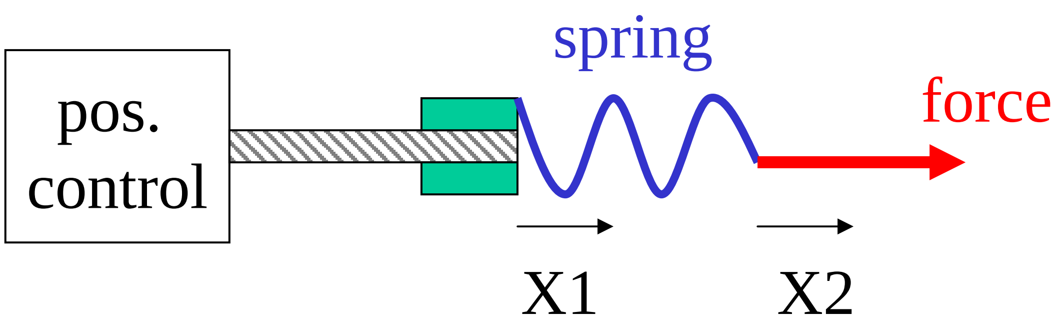




Force control

from position to force control





$$F = c \cdot dX$$

Force control

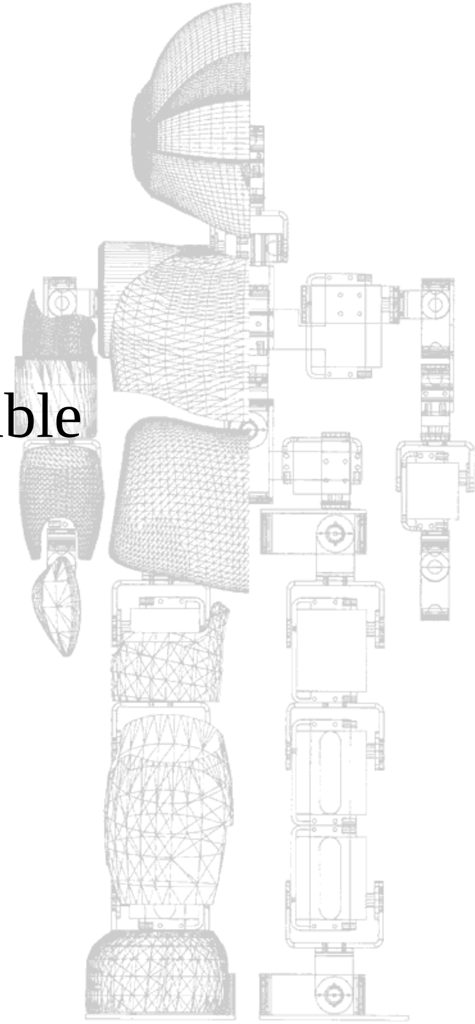
series elastic actuators [Pratt G. 1997]

-improve shock tolerance
-use cheap motors
-use energy storage

Movie Flamigo-walking

Position control

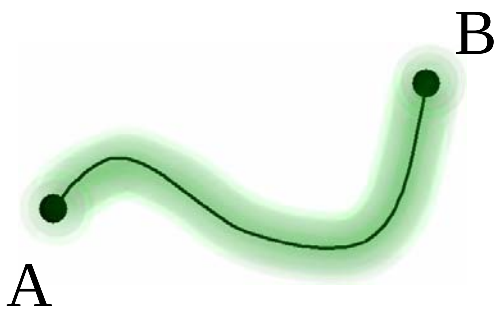
Discussion position control loop

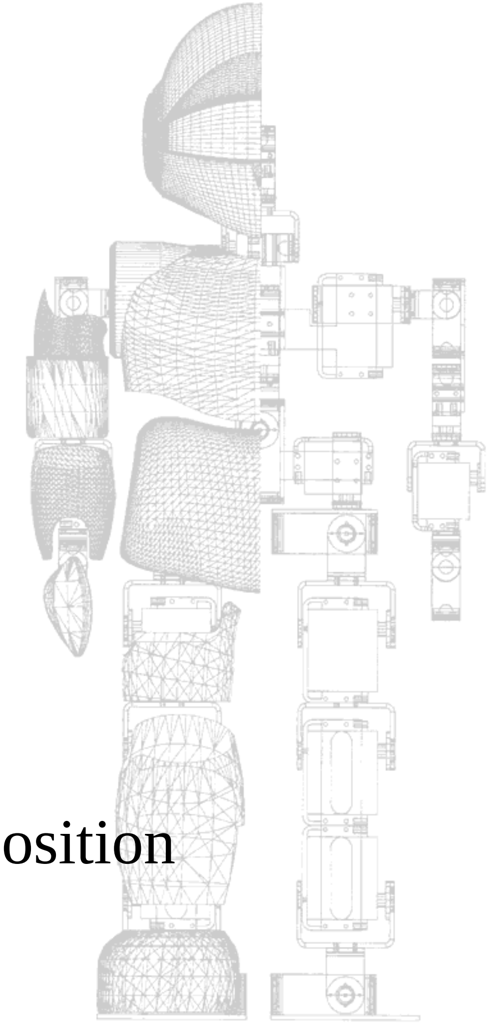


- Simple & effective technique = cheap !!
- Easy extension to trajectory control
- Parallel control loops for multiple DOFs possible
- Most frequently used type of control
- More complex control algorithms possible
- Also usable for speed & force control
- Optimal gain settings depend on the load

Types of movement control

force/position control





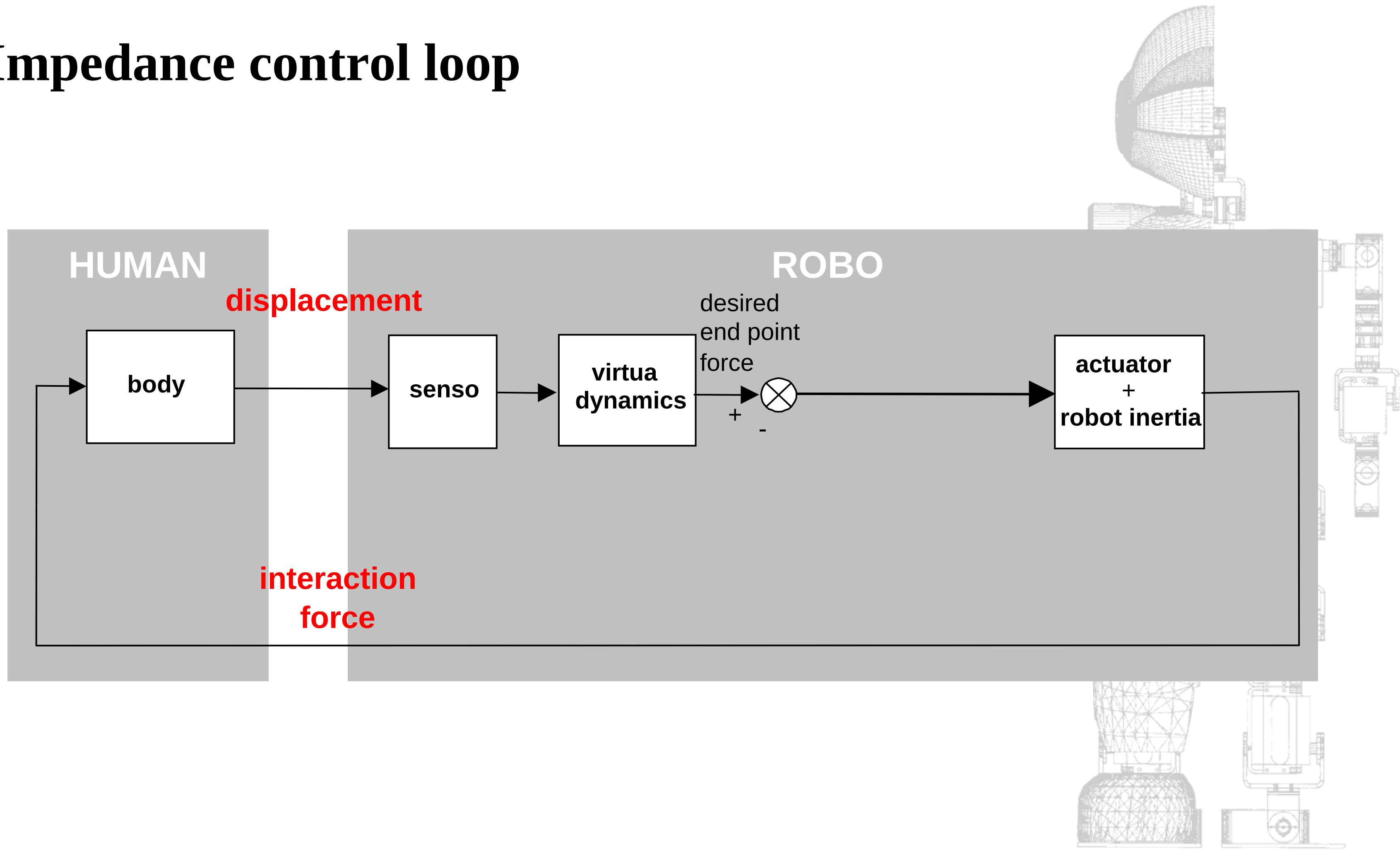
When ?

•simultaneous control of force & position

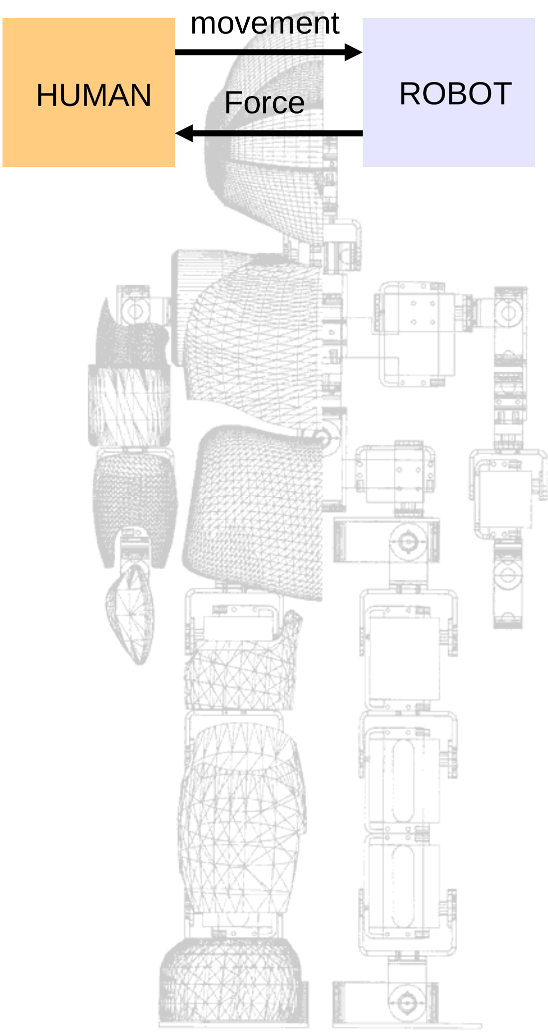
e.g. reaching, human interaction

Force/position control

Impedance control loop



Force/position control



Discussion impedance control loop

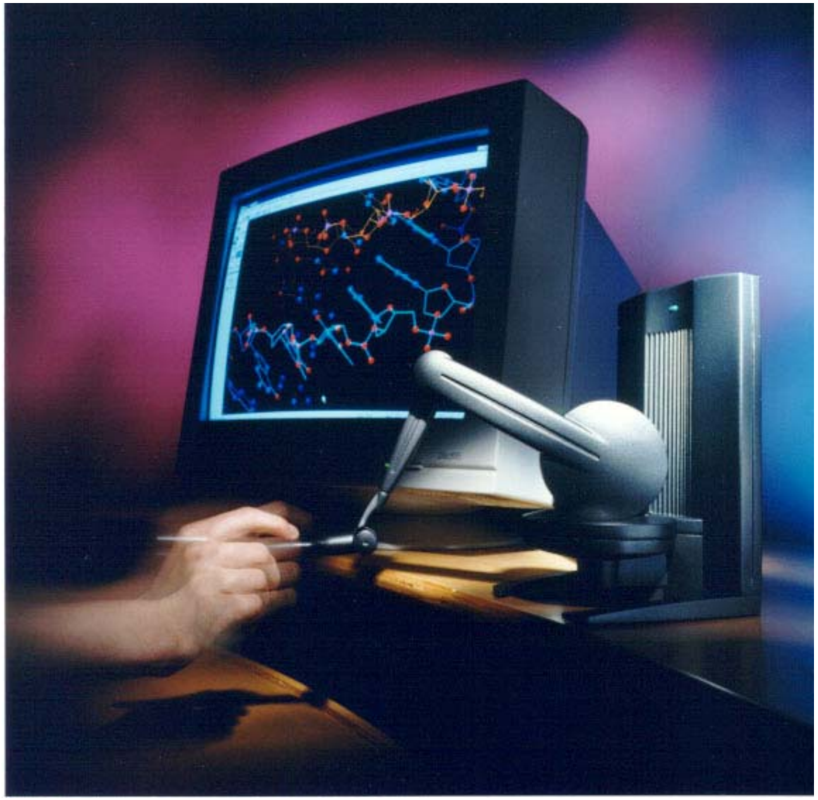
- no elimination of robot inertia
- no elimination of mechanical friction
- measure displacement before giving force
- no force sensor required

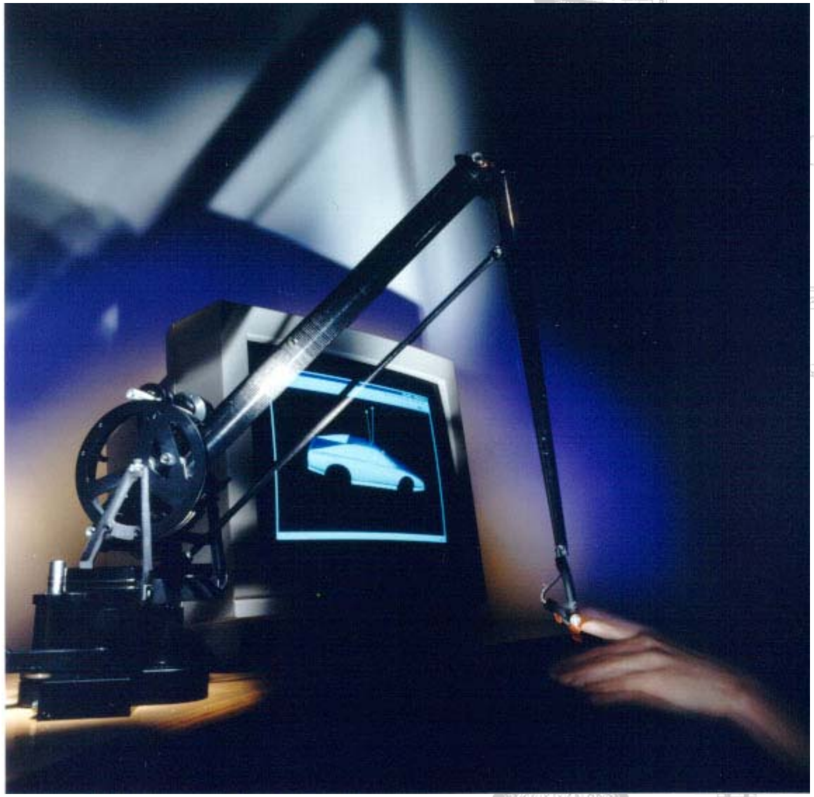
conclusion:

good for soft & light tasks, high safety !

Force/position control

Example impedance controlled devices

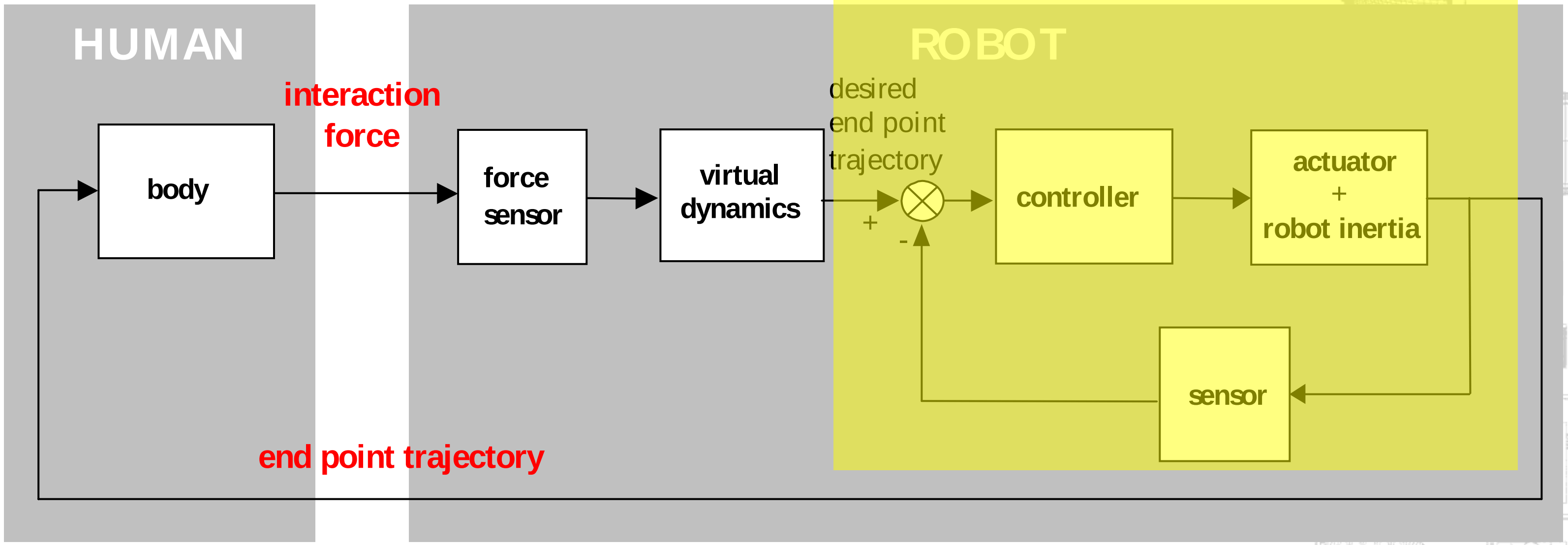




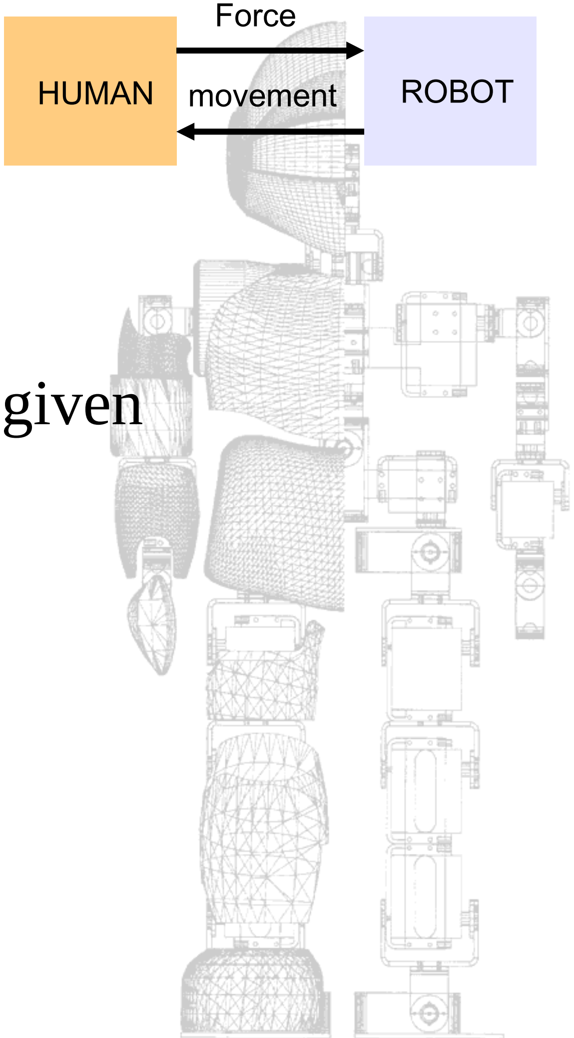
Force/position control

Admittance control loop

position loop !



Force/position control



Discussion admittance control loop

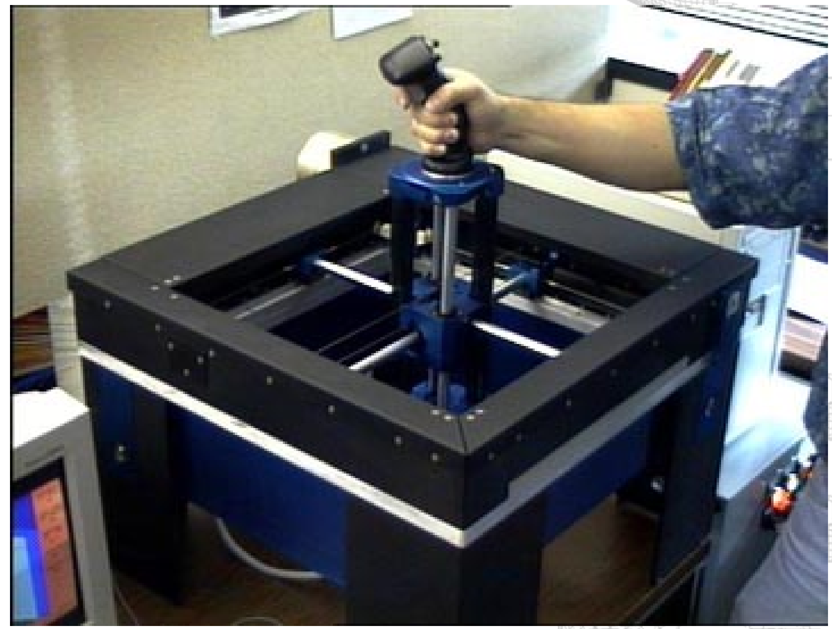
- limited elimination of robot mass & inertia
- measure force change before displacement given
- force sensor required
- instability for very high gains

conclusion:

good for hard & heavy tasks, lower safety

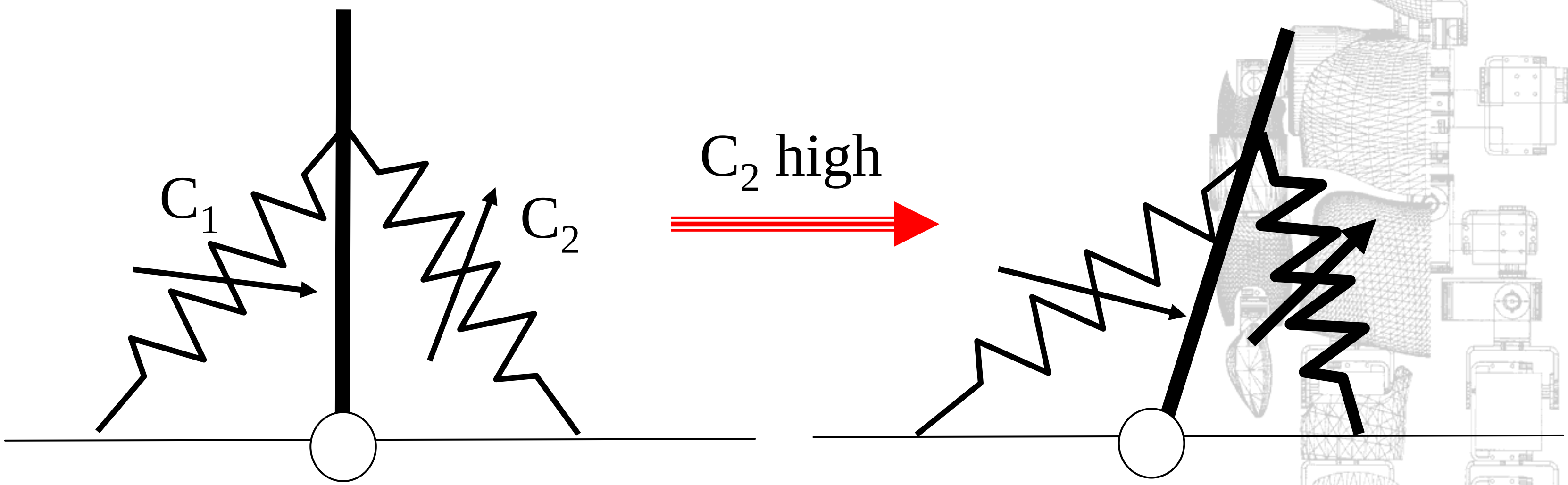
Force/position control

Example admittance controlled devices



Force/position control

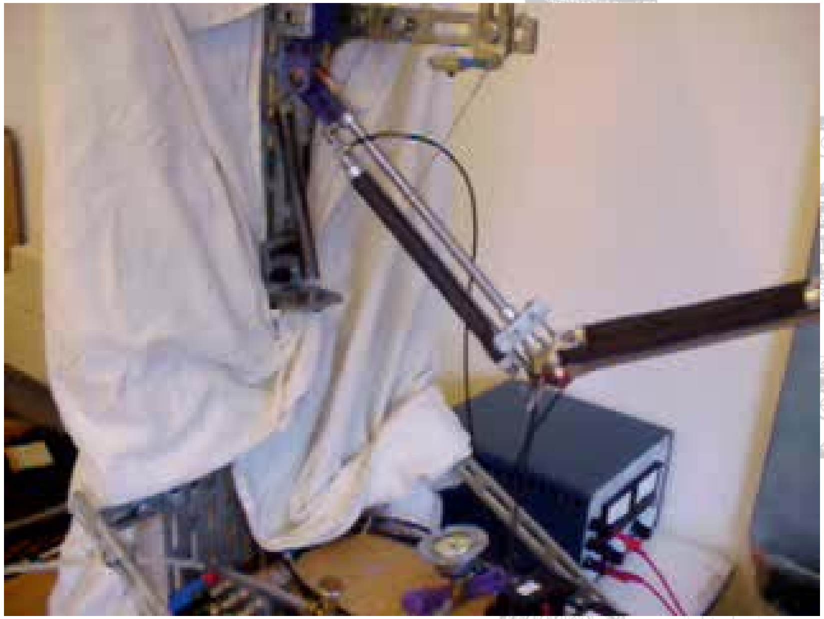
Using actuator intrinsic properties



equilibrium point hypothesis, Feldmann

Force/position control

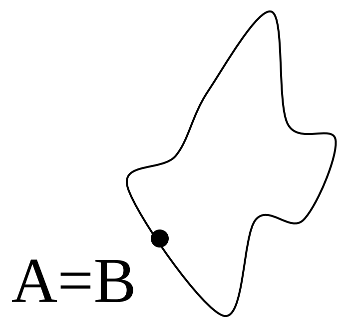
Example

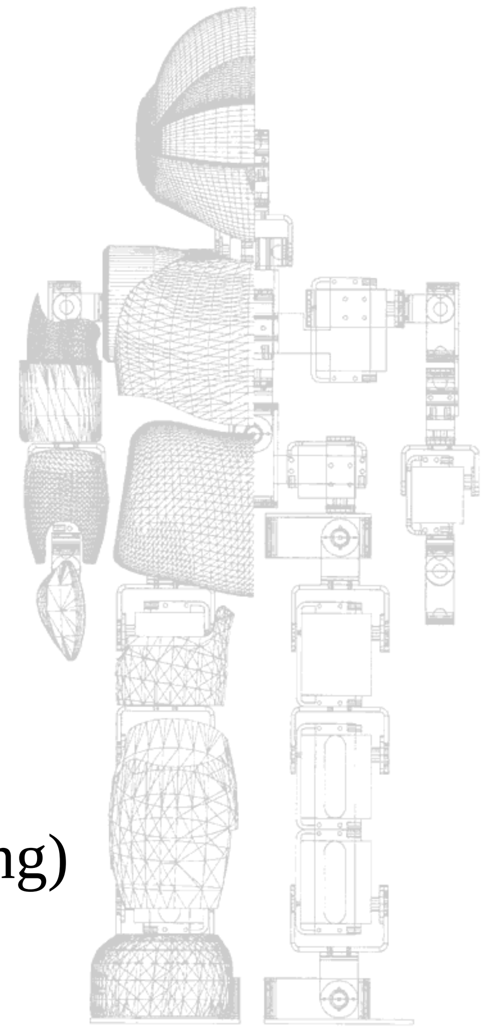


DUT, DBL
6 muscles, 4 DOF

Types of movement control

periodic control





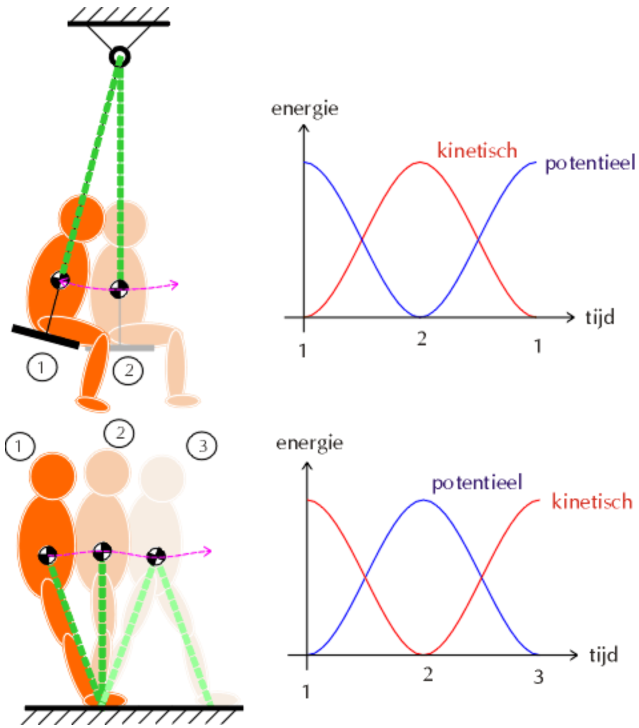
When ?

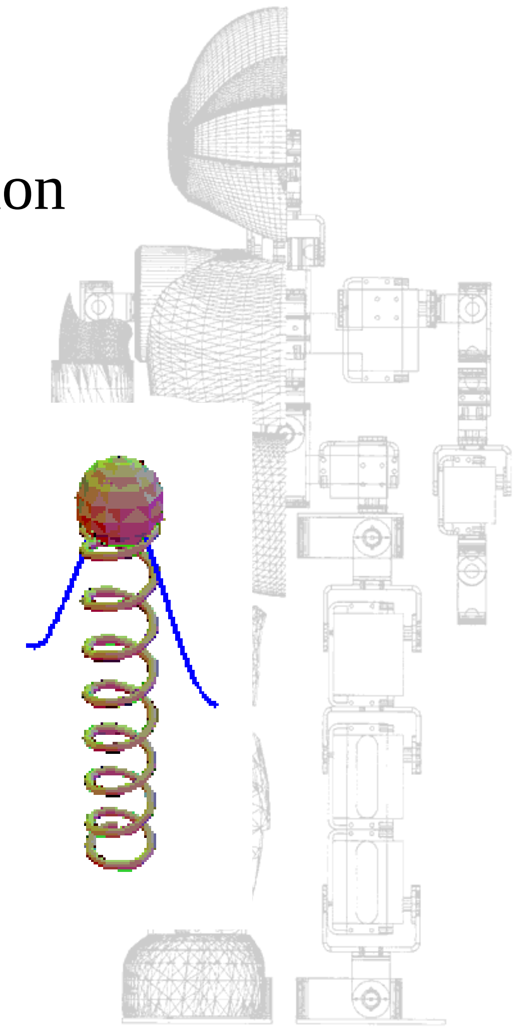
•repetitive motion (e.g. walking)

Periodic control

Intrinsic periodic movement

use mass-spring properties to generate oscillation





Periodic

Examples

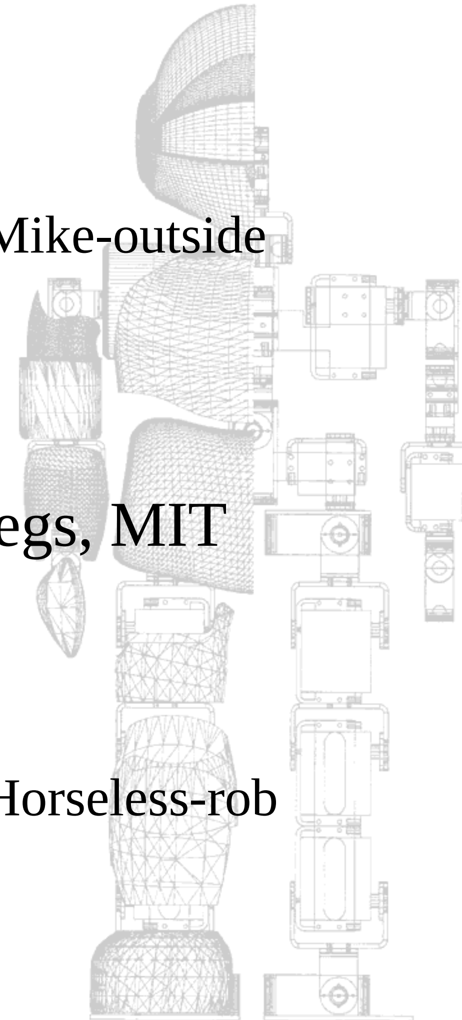
"passive" walking, DUT

Movie Mike-outside

springy legs, MIT

Movie Museonside

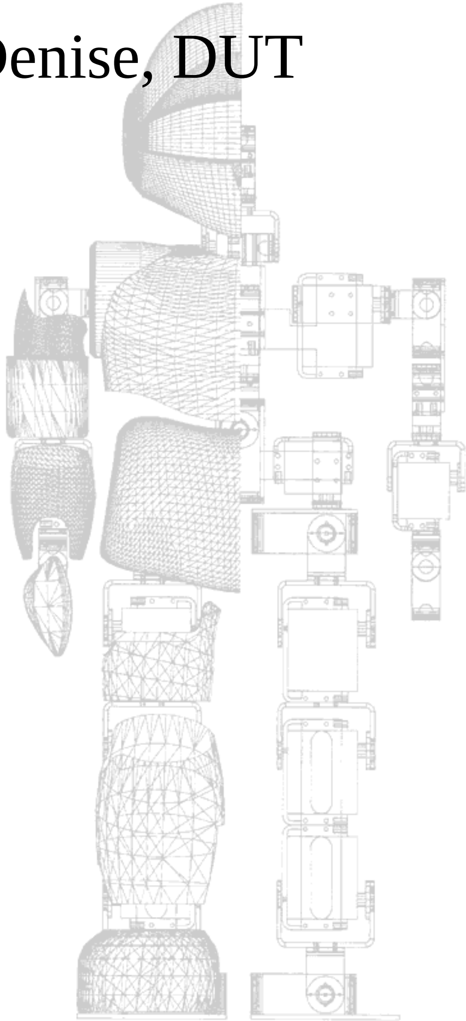
Movie Horseless-rob



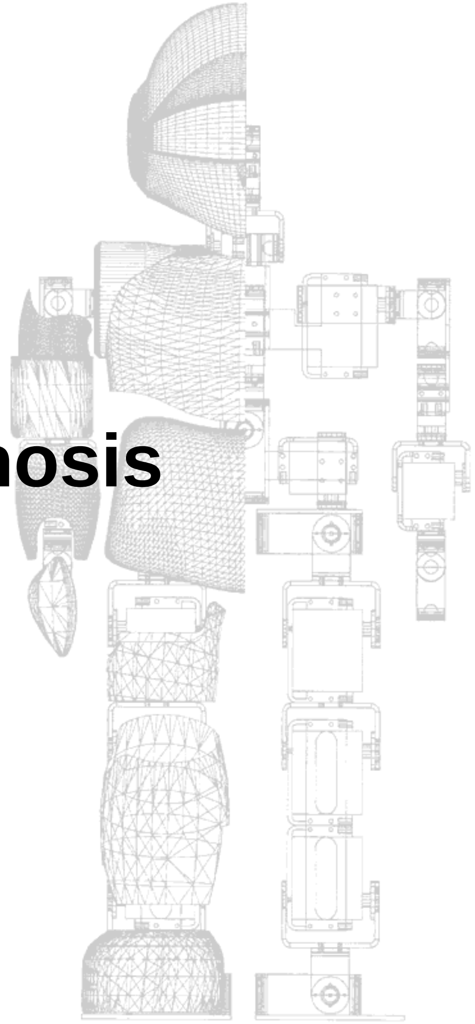
Periodic

Example: "passive" walking, Denise, DUT

Movie Denise-3



Robot identification & diagnosis

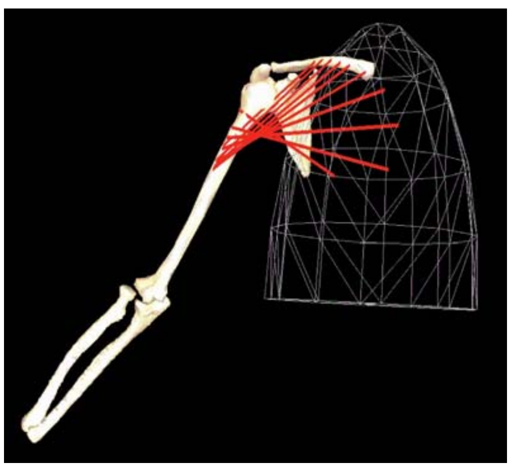


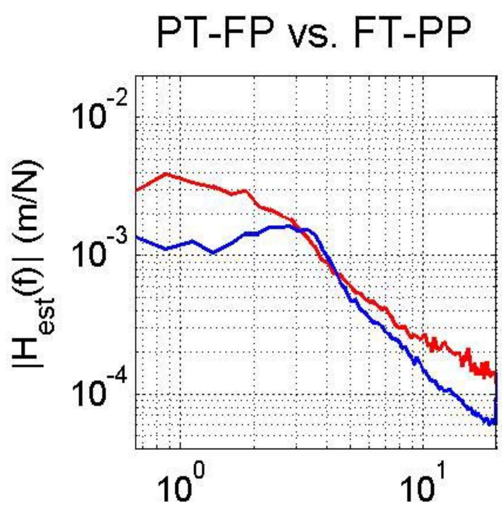
Delft University

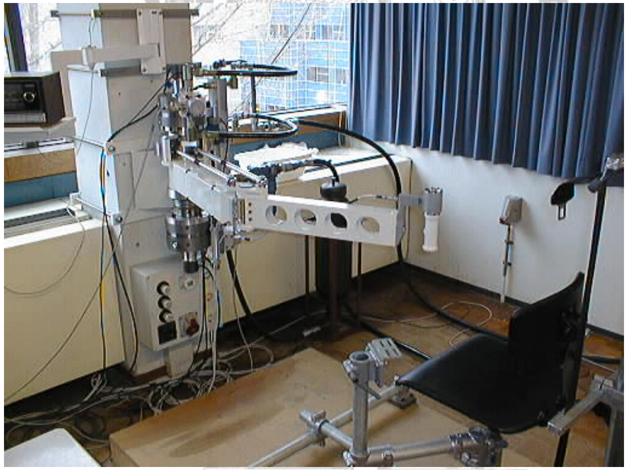
Delft Shoulder Group

- neuro-muscular modeling
- parameter identification by perturbation
- frequency domain approach
- new diagnosis tools ?

Admittance controlled devices







robot therapy

Gentle

Movie Gentle

Gentle

Goal

The aims of GENTLE/S will require established stroke rehabilitation practices to be altered to accommodate machine mediated therapies

Results

- 8 subjects found therapy motivating
- no clinical data available yet

Admittance controlled device

set up (4 DOF)

on-going research

Gentle

mechanics Haptic Master

force sensor

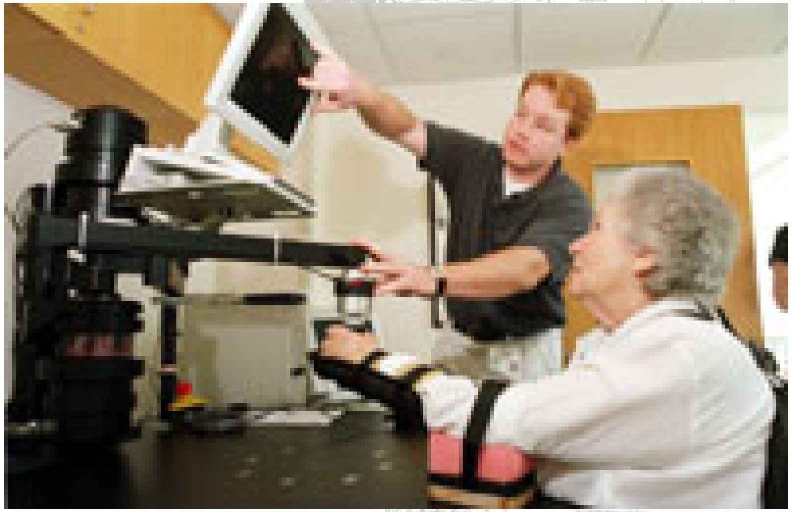
MIT MANUS

goal:

The goal of the project is to develop, implement and test a robotic system for physical therapy and neurological rehabilitation.

motivation:

- Some 700,000 US citizens suffer strokes every year
- Cost of care 30 B$
- Of these, some 500,000 require therapy for problems with language, memory or movement.
- The MIT robot focuses on the last of these



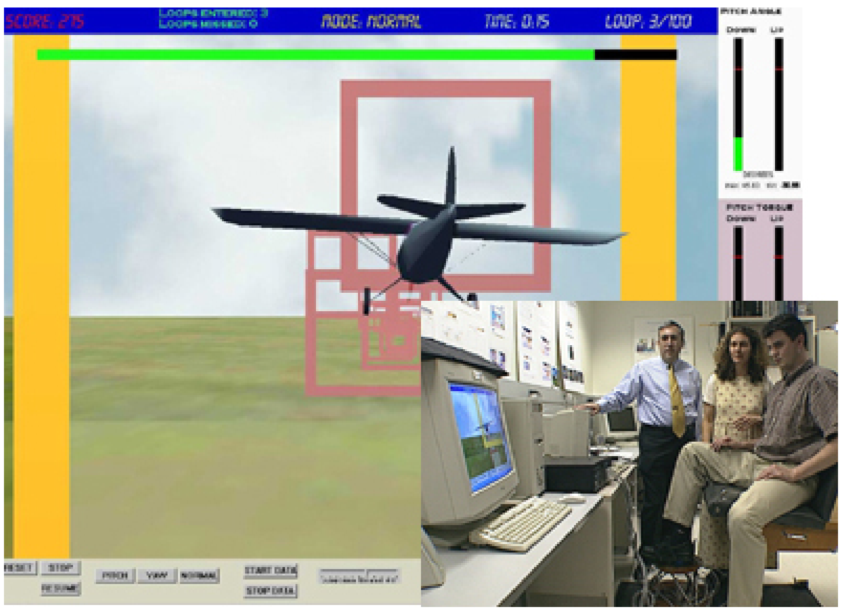
set up (3DOF)

Impedance controlled device

Rutgers Ankle

Motivation

The Rutgers ankle is for patients that need ankle and knee rehabilitation, both for orthopedic and stroke diagnoses



interface

6 DOF Steward platform

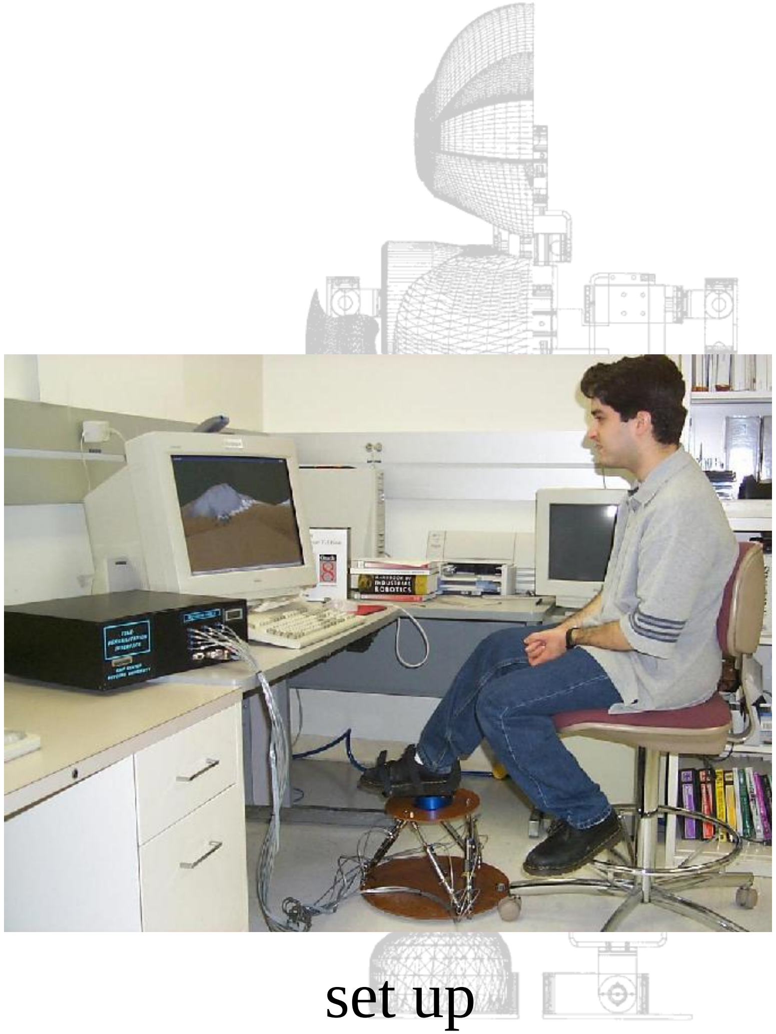
Rutgers Ankle

experiments:

3 ankle sprain subjects

results:

- improvements in range of motion
- improvements in torque generation cap.
- improvements in ankle work

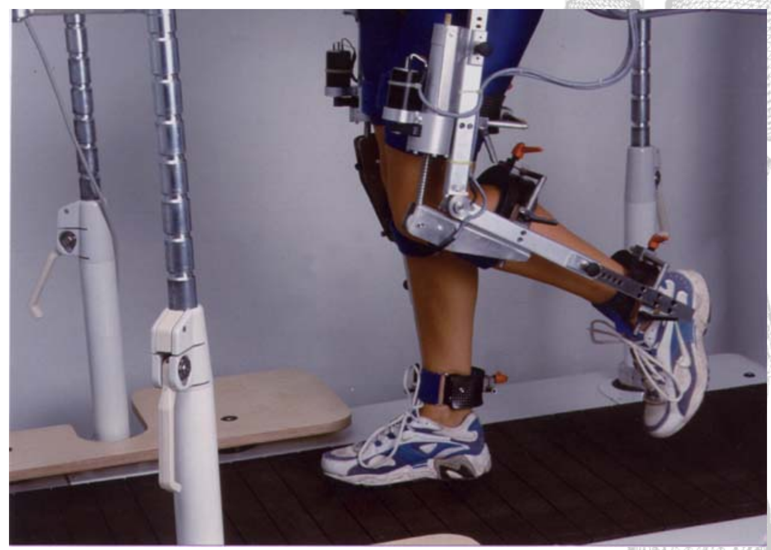


set up

Lokomat

Hacoma, Zurich

- commercial device !
- gait generation (no impedance, just position!)
- spinal cord injuries
- mainly research applications



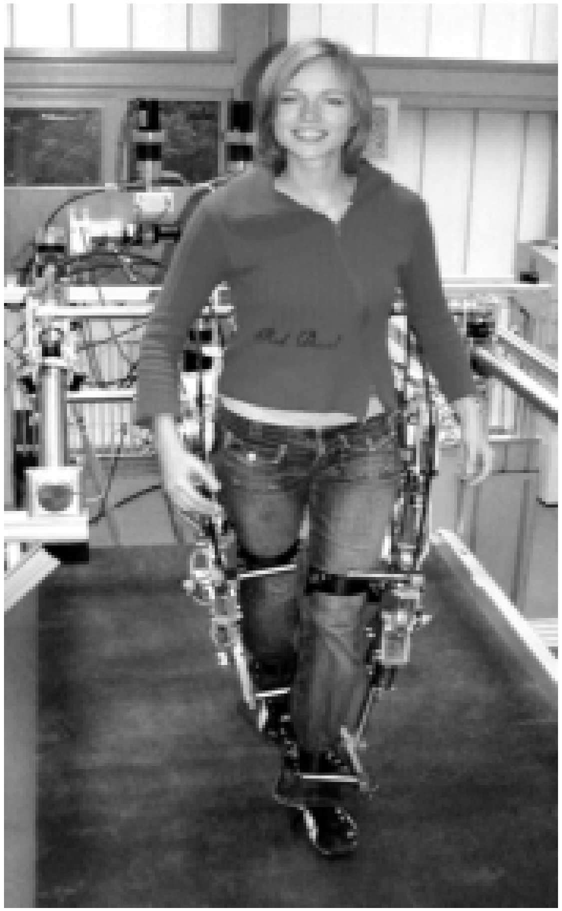
Lokomat

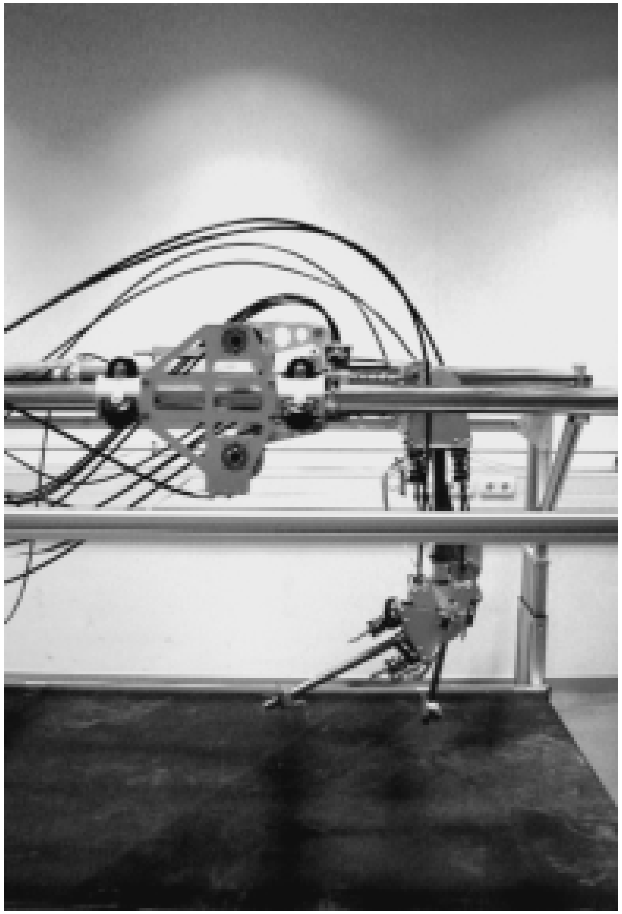
Movie Locomat I

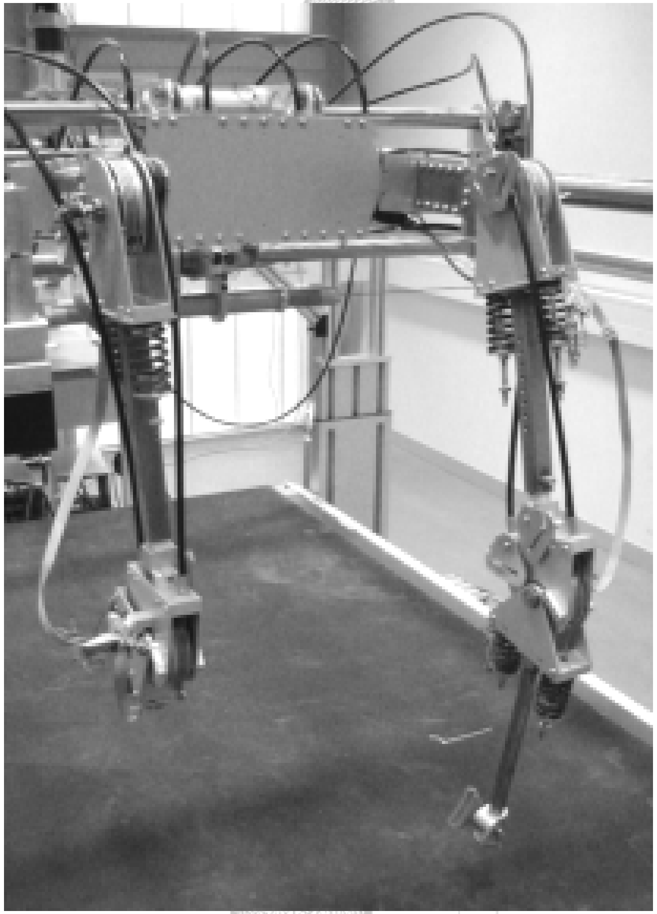
Lokomat

Movie Locomat II

Lopes – University of Twente







Lopes – University of Twente

Movies Lopes I & II

assistive robots

Wheelchair robots

Uses:

- self care
- cooking
- shopping
- scratching
- ...

Autonomy !

Wheelchair robots

Movie Beyond

Wheelchair robots

Design criteria

- stability
- Joystick input
- End point control
- Safety (close to the face)
- Movement repertoire
  - -eating
  - -page turning
  - -pouring
- (Voice recognition)
- price (below 30k Euro)
- autonomous

"Manus ARM", Exact Dynamics

2 kg load
20 kg weight
25.000 Euro

Living assistance

Care-O-bot
Fraunhofer IPA

Movie Care-O-bot

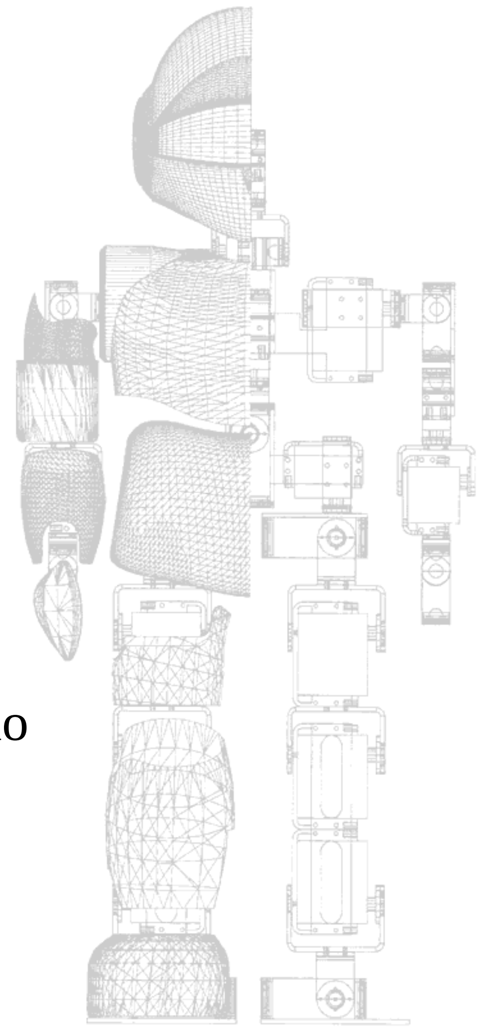
Carebot
Gecko Systems

Living assistance

HONDA Humanoid
- Fully assistive household (future)
- Remote controlled operations

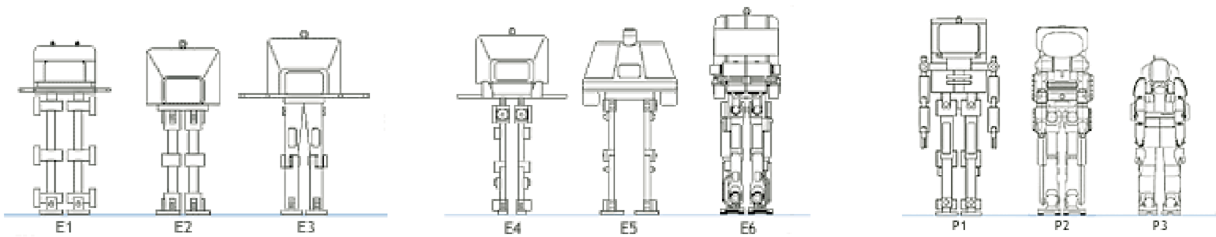
Specs
- Walking & turning (i-walk)
- Maneuvering (e.g. stairs)
- Stereo vision
- 26 DOFs
- Intelligence ?
- 250.000 Euros

Movie Asimo

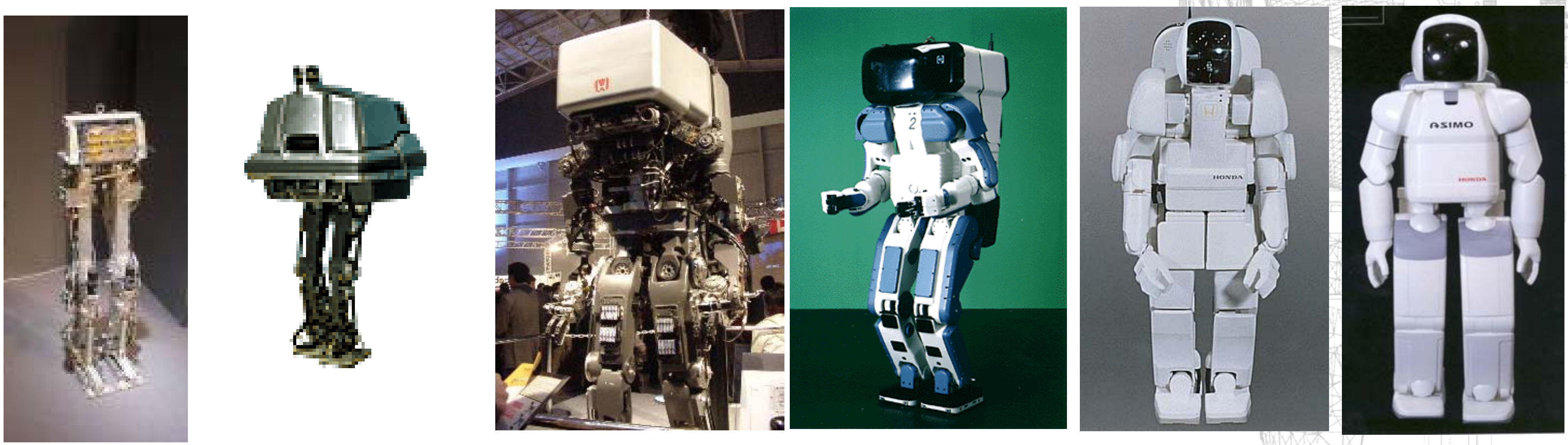


Living assistance

1986 1991 1993 1996 1997 2000



E0-E3 E4-E6 P1 P2 P3 Asimo



P1	P2	P3	Asimo
175 kg	210 kg	130 kg	52 kg
1.9 m	1.8 m	1.6 m	1.2 m

~500.000.000 Euros development costs

Living assistance

Movie Asimo on Stairs

Movie Asimo Running

Honda Asimo

Cleaning & domestic

Specialized functions:

- Vacuum cleaning
- Lawn mowing
- Window cleaning
- Floor cleaning

Key technologies:

- Obstacle avoidance
- Environmental map making
- Path planning
- (Energy supply)

"Roomba"

"SIRIUSc"

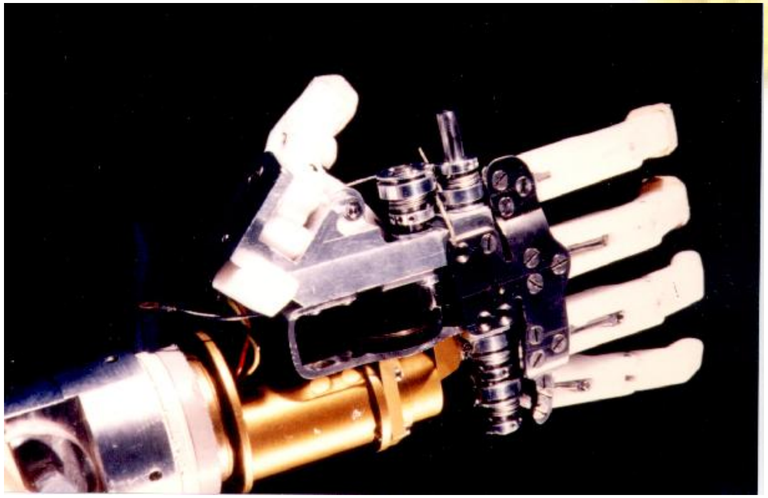
"Trylobite"

solar mower

Prosthetics

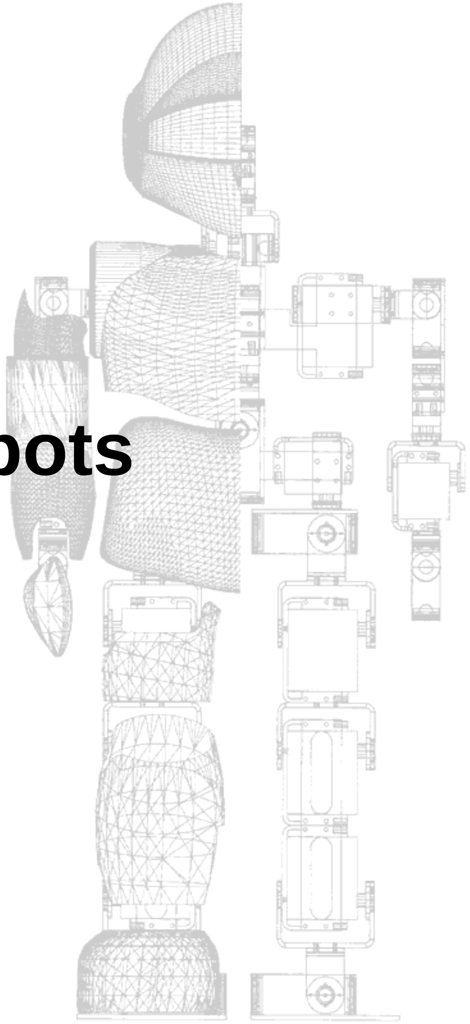
Main issues

- communication with the human body
- weight (stump load, energy consumption)
- controllability
- cosmesis
- durability



storing energy in elastic deformation

electronically controlled knee



Future on rehabilitation robots

Numbers & trends

predicted number of service robots installed

(World Robotics 2002, 2006; The Int. Fed. of Rob., United Nations)

segment	up to 1999	2000-2003	2005
cleaning	400	700	5370
underwater	900	200	5680
medical	800	5.000	3475
rehabilitation	200	200	n.a.
domestic	3.000	310.000*	$1.9x10^{6}$**
entertainment			$1x10^{6}$
other	1.300	4.300	12.000
total	**6.600**	**319.400**	**$\pm$ $3x10^{6}$**

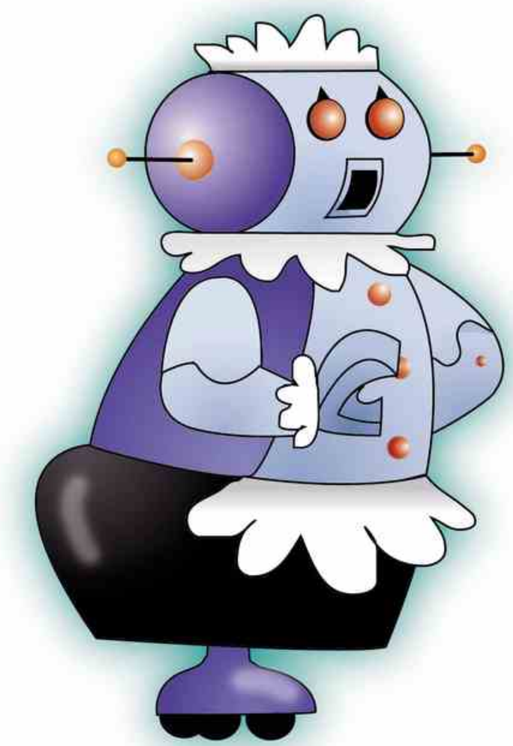
* = 270.000 vacuum cleaning

** = $1.8x10^{6}$ vacuum cleaning

Future perspective

Activities in the field announce an exciting future:

- Robotic technology is evolving rapidly
- Robotic systems in the (toy) store
- Robotic systems in the operating room
- Robotics systems at home
- Robotic systems in the media
- Robotic (sub-) technologies in other fields



Robotic systems are entering our life !

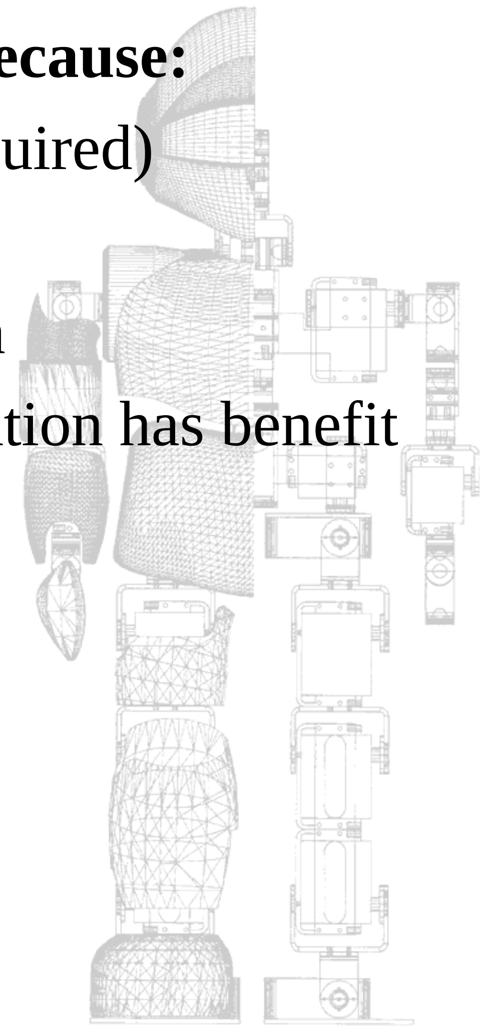
But rehabilitation robots ...

...many questions to be answered

Future perspective

Rehabilitation robots is still a small market because:

- QALY is very low (so cheap technology is required)
- therapy: no proven efficiency yet, upcoming
- identification: complex, needs a lot of research
- prosthetics: too complex, relative small population has benefit
- assistive: due to large market great future



Change drivers:

- aging population
- technology advancement

Wheelchair robots: ARM

Movie ARM