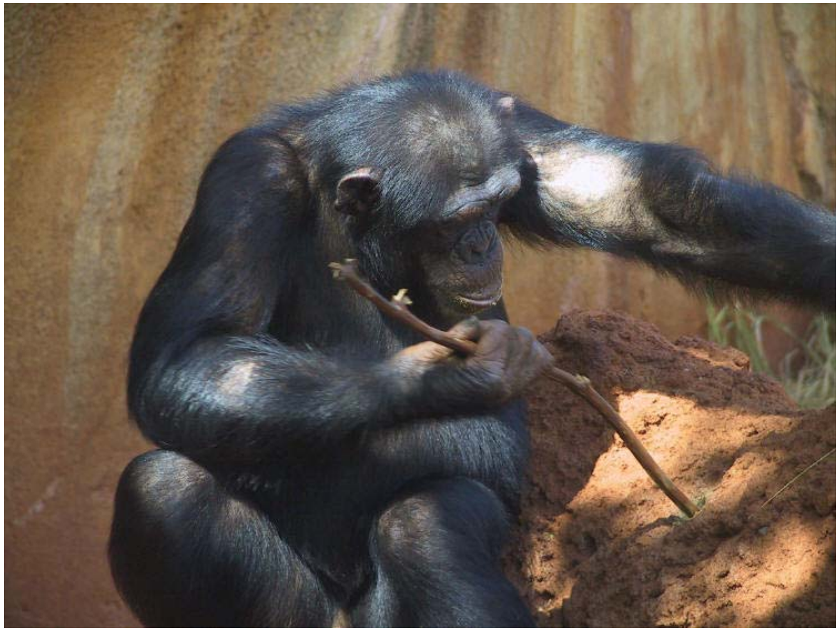
# Systems & control
# Inspired by Biology



**Systems & control: challenges in the 21st century**

**Richard van der Linde**

**Delft University of Technology, Delft Biorobotic Laboratory & Altran Technologies Netherlands**



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# Contents

- **Who are we ?**
- Introduction biorobotics
- Lessons learnt so far
- Conclusions
- Challenges for the $21^{st}$ century



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# Who are we ?

The world

TUD, Mechanical Engineering

**Man Machine Systems**
Prof. F.C.T van der Helm/Prof. P.A. Wieringa

**Delft Biorobotic Laboratory**
R.Q. van der Linde (ass. prof)
M. Wisse (PhD student)
D. Hobbelen (PhD student)
G. Christiaanson (PhD student)
A. Schiele (ESA PhD student)
J. Frankenhuyzen (Eng.)
E. Fritz (Eng.)



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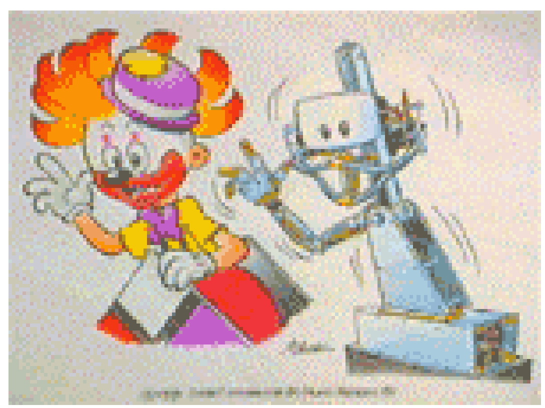
# What do we do ?

*Biorobotics is robotics inspired by biological systems*

## Key projects in the DBL:

| | | |
|---|---|---|
| • Efficient & stable walking | 1995 | STW |
| • Safe manipulator | 1999 | TUD |
| • Biocompatible grasping | 2002 | VENI |

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# A new generation of robotics is coming

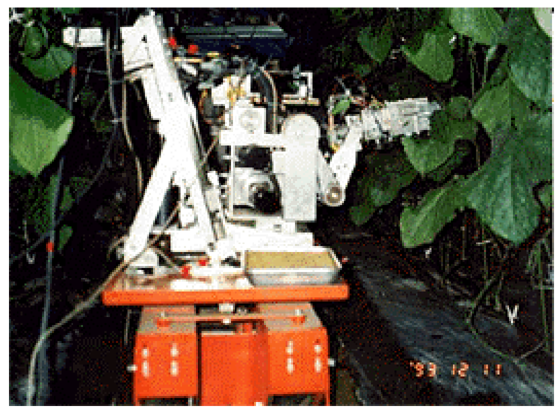

rehabilitation

wheelchair robotics

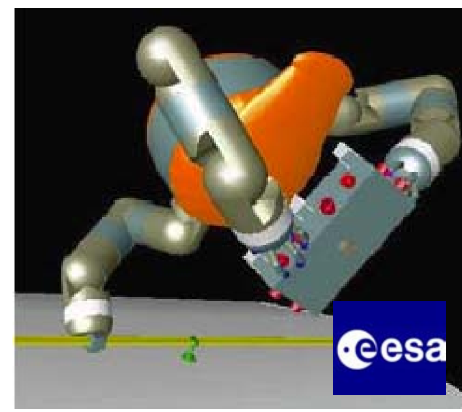
home robotics

entertainment

medical robotics



agro robotics




space robotics

# Interaction with biological systems requires a different control approach

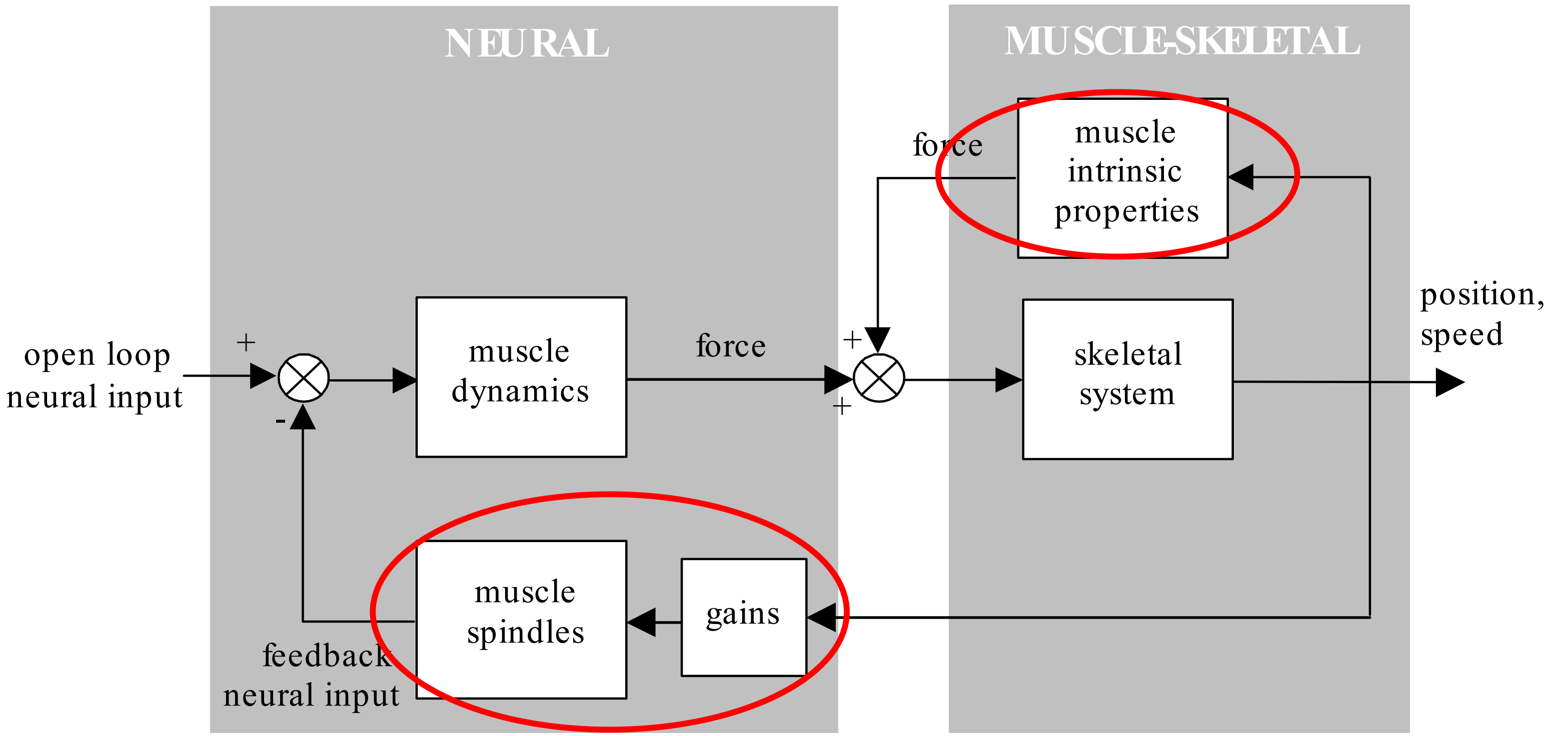
## Biological inspiration = Biorobotics

Useful properties of biological systems:

- **stable** interaction
- **adaptive** to environmental conditions
- **safe** interaction
- **simple** solutions

Because we design for biological systems

# Human CNS control scheme




F.C.T. van der Helm

# Also, biological and artificial systems have different system properties !

| | human | technique |
|---|---|---|
| • delay time | 50-120 ms | 0.1 - 5 ms |
| • # sensors hand | 17.000 | ~ 10 - 40 |
| • # sensors eye | 12 Mp | ~ 0.3 - 1 Mp |
| • # actuators | 639 | ~ 20 - 40 |
| • # DOFs | ~ 200 | ~ 20 - 40 |
| • # op. units | 50 - 100 $e^{12}$ | 4 - 100 $e^{7}$ |
| • power cons. | 100 W | 4000 W |

**Different solutions !!!**

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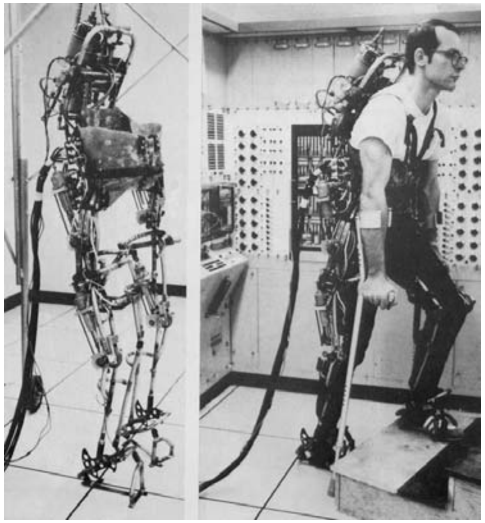
# Efficient & stable biped walking

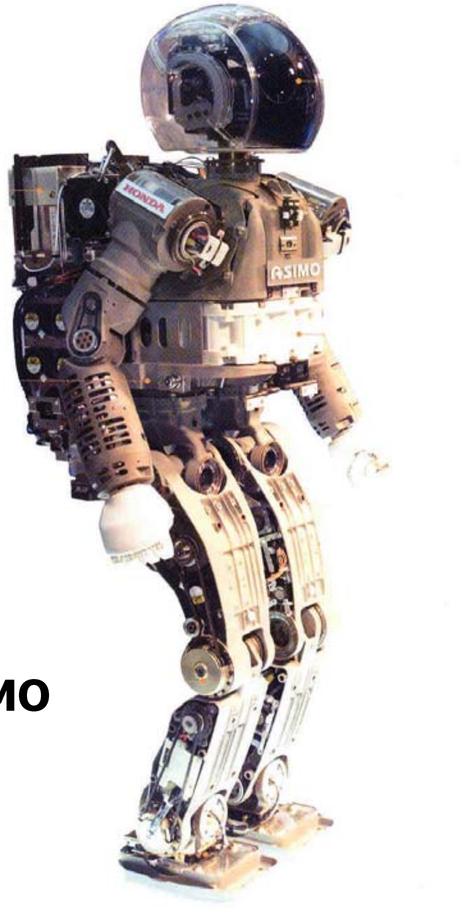
**Problem:**

Energy consumption

(price, complexity, non-natural)



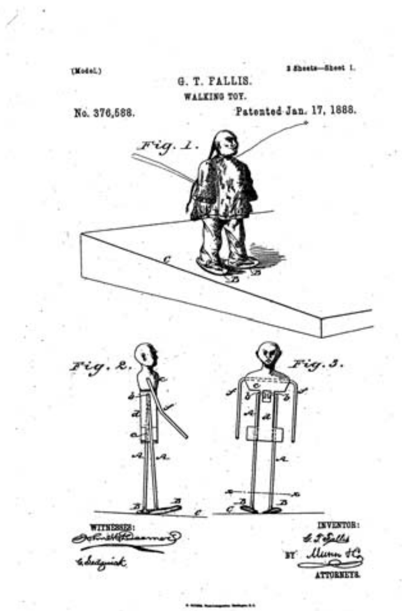
**Honda ASIMO**
**•43 kg**
**•15 min.**
**•26 DOF**



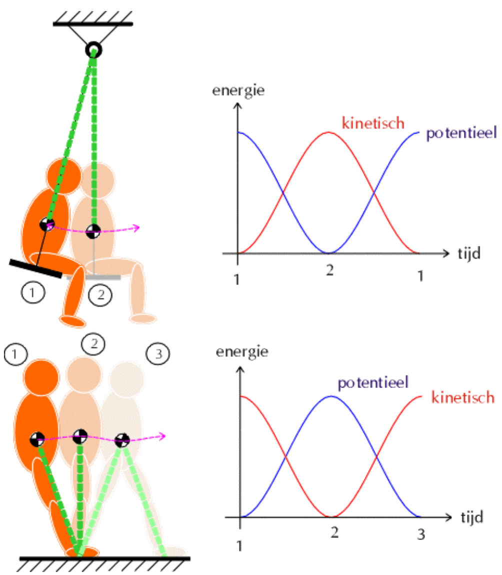
# Efficient & stable biped walking

**Solution:**

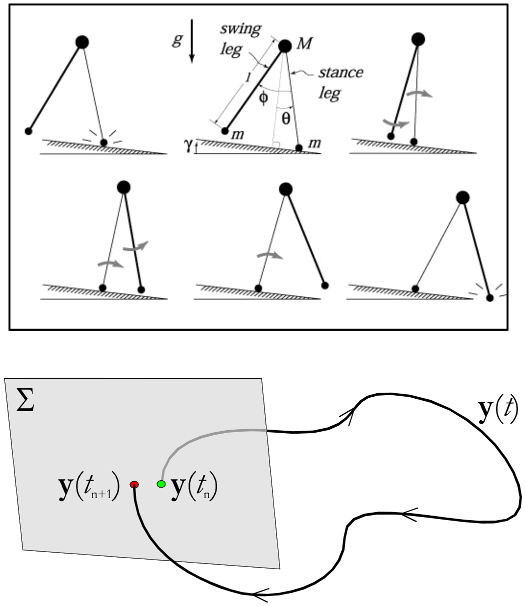
Exploiting ballistic motion, creating stable limit cycles




**`1888 patent**




**free swinging motions**



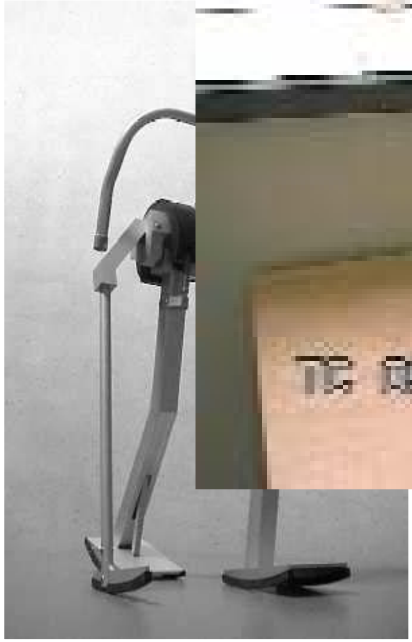

**limit cycle analysis**

# Efficient & stable biped walking

**gravity powered devices**

2000

2001



2002

M. Wisse

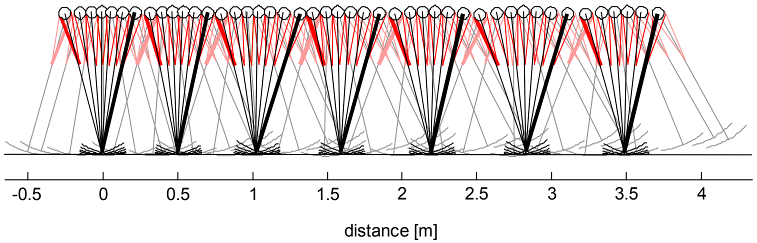
# Efficient & stable biped walking

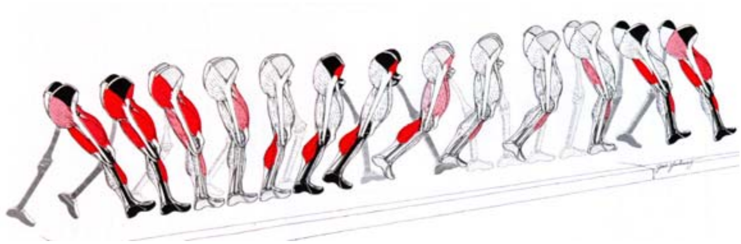
**Problem:**

Activation & control

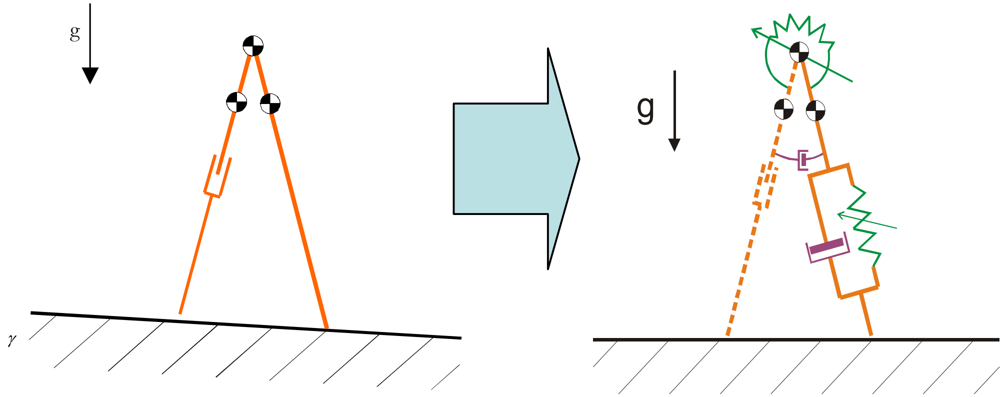
**Solution:**

phasic variation of passive stiffness



**Inman, 1981**



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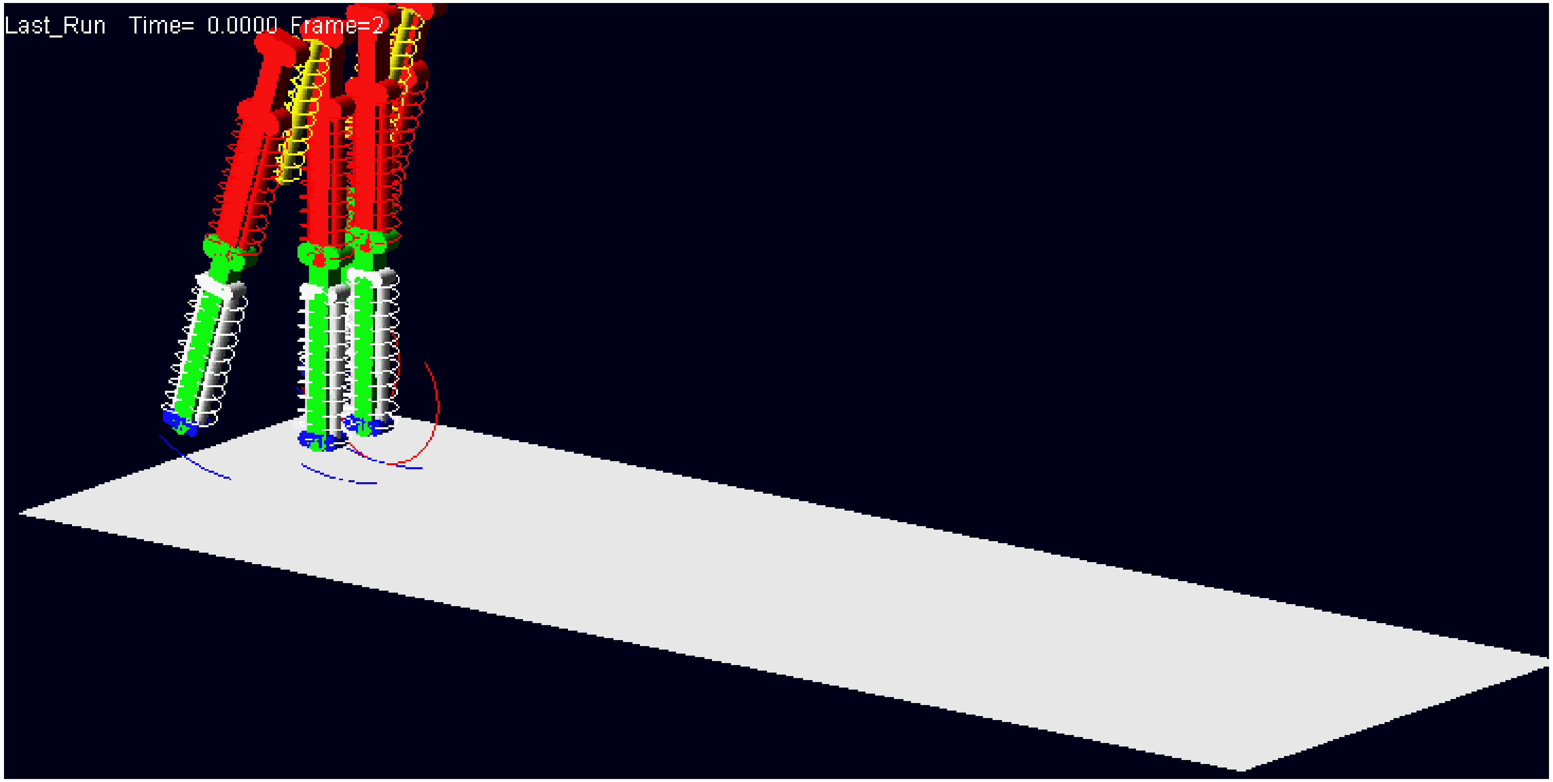
# Efficient & stable biped walking

## A simulation result:



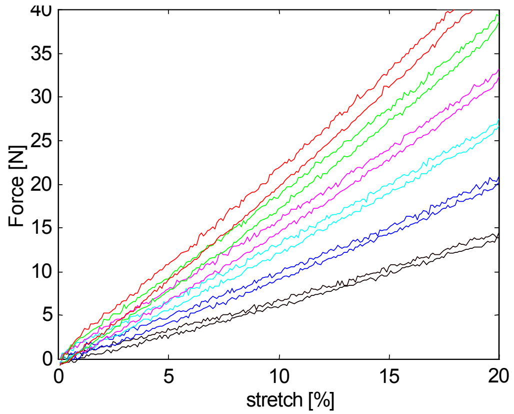
# Efficient & stable biped walking

**Problem:**

How to make efficient active springs

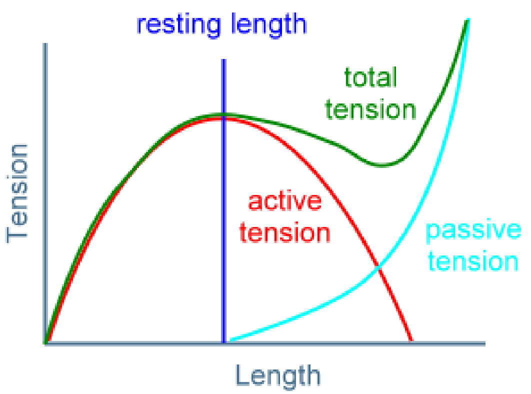
**Solution:**

Pneumatic (McKibben) muscles




stretch force curve of McKibben muscle

=




Length-Tension Curve of a Muscle



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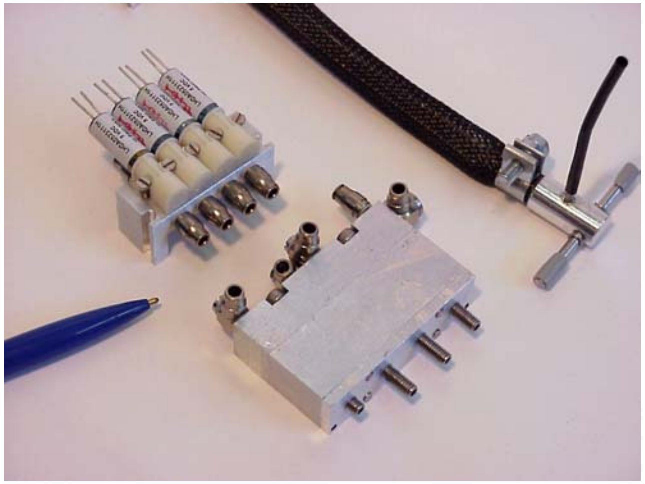
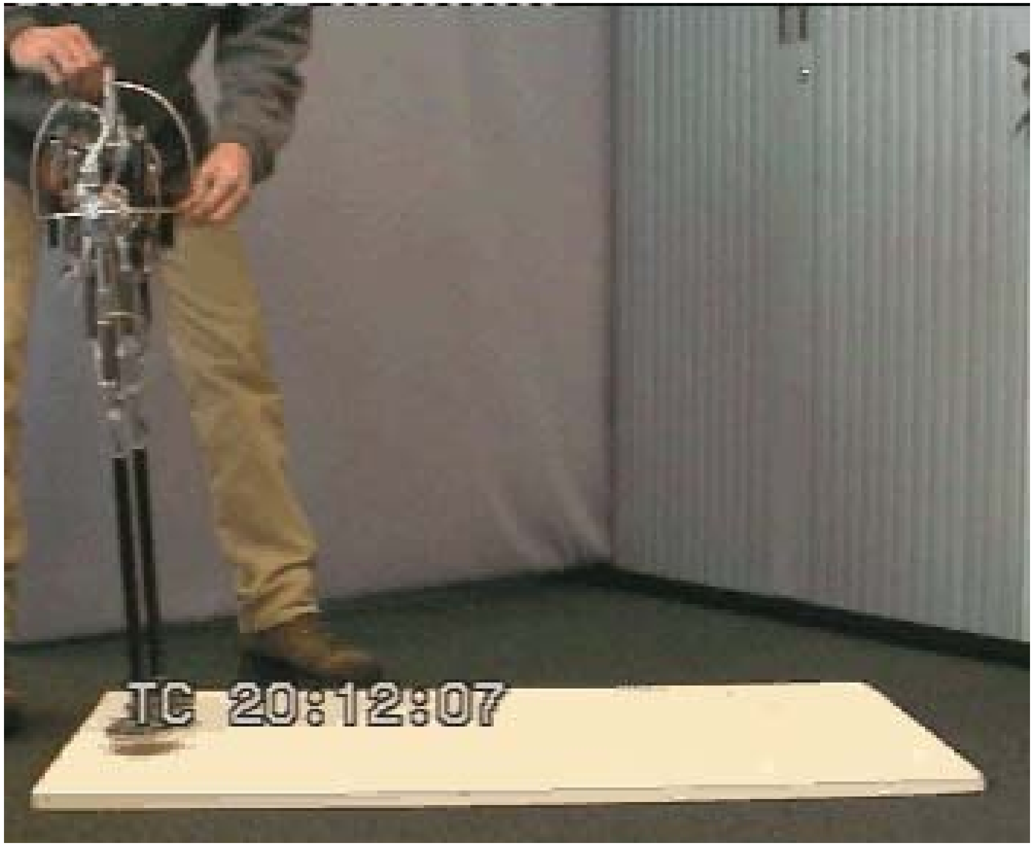
# Efficient & stable biped walking



developed pneumatic components + PC104 controller

**The first steps (2002)**




**Baps**

- 3.4 kg
- 16 W (15 W elec.)
- 11 steps
- 3D

# Efficient & stable biped walking

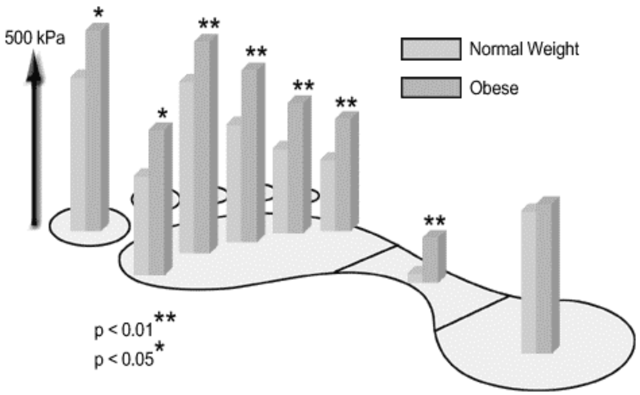
**Problem:**

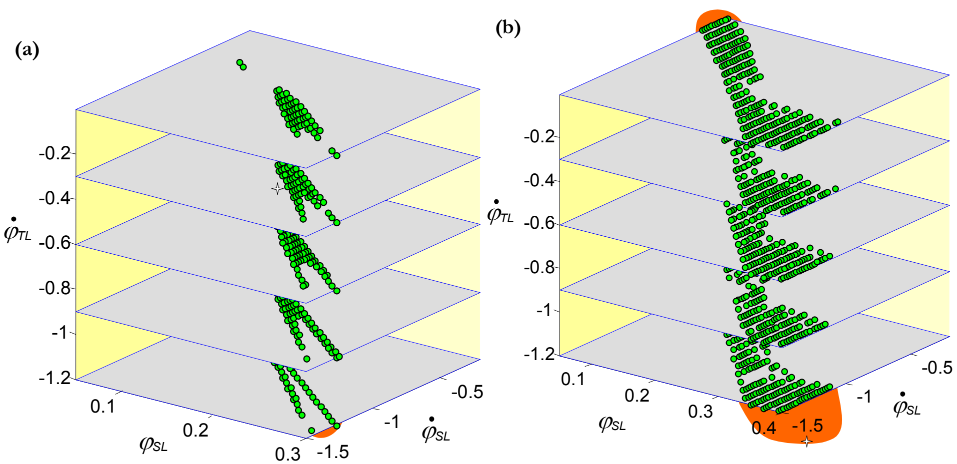
Achieving cycle robustness

**Solution 2:**

Mechanical Optimisation

(spherical feet, DSF)




no feet

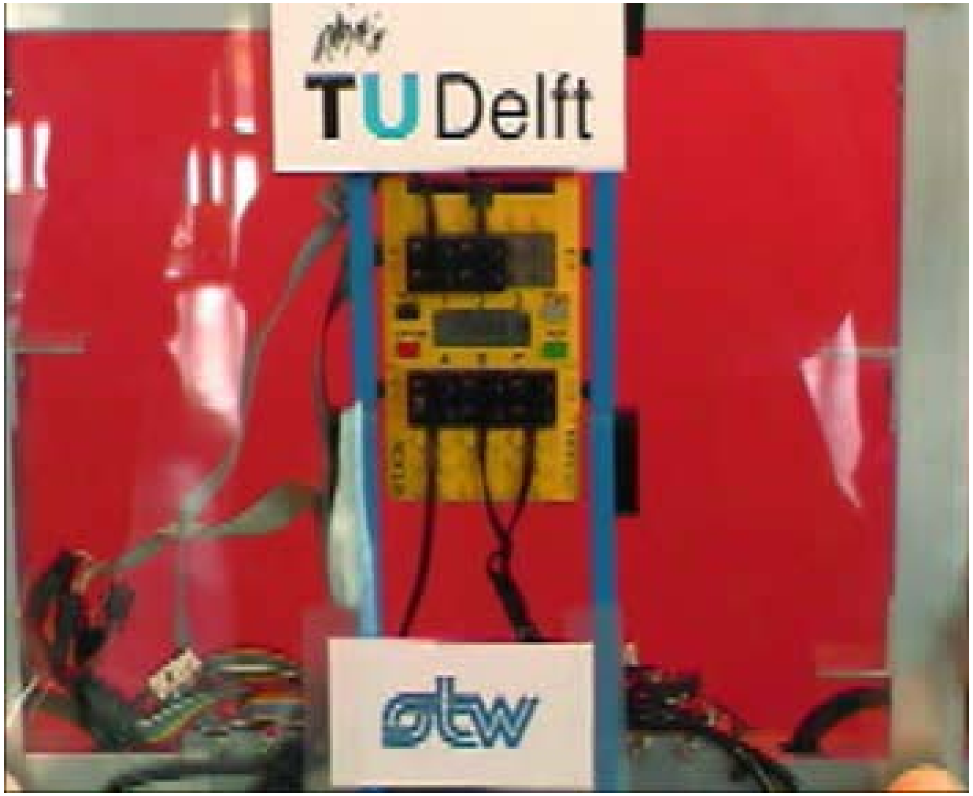
feet (R=0.5 L)

# Efficient & stable biped walking

**Successful solution**

simple reflexes:

- stretching the knee
- swinging the hip




**Max**

- **10 kg**
- **LEGO brick control**
- **∞ steps**
- **2D**

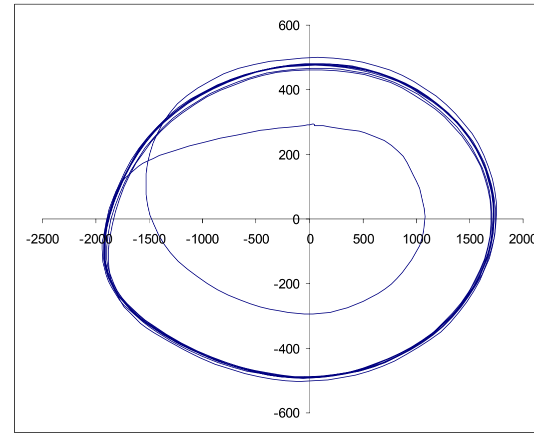
# Efficient & stable biped walking

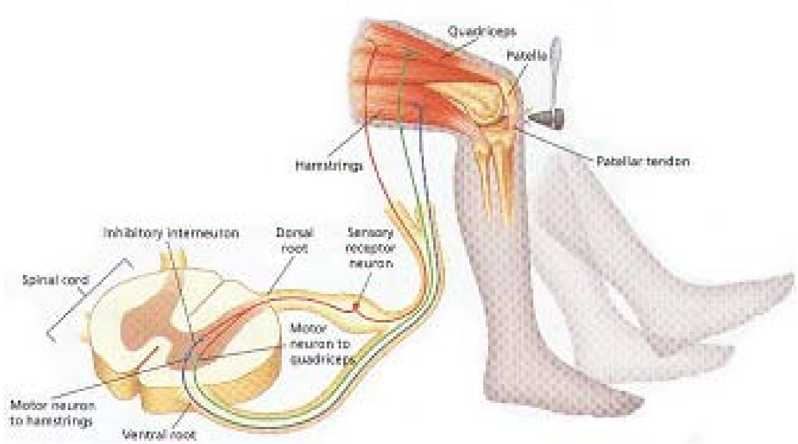
**Problem:**

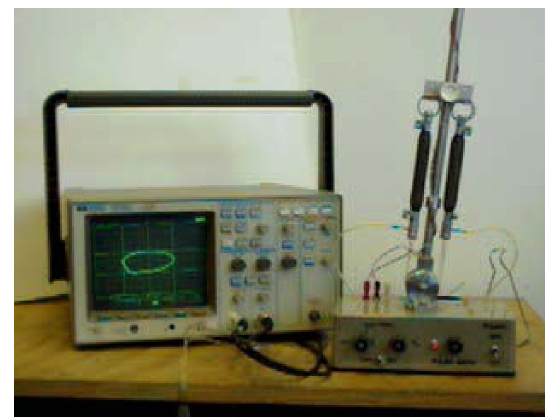
Achieving cycle stability in 3D

**Solution:**

Adaptation of reflexive control ?



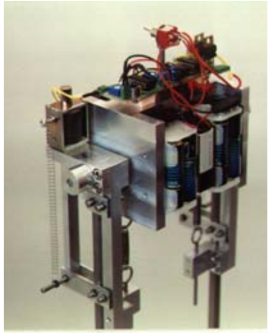



**Limit cycle dead beat control**

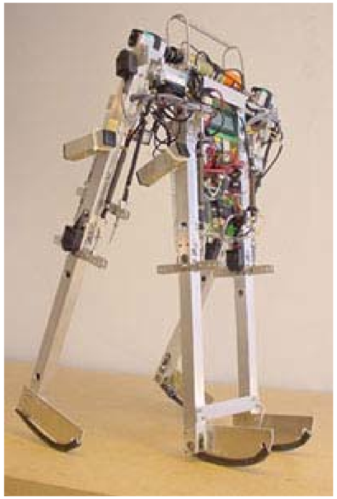
# Efficient & stable biped walking

(muscle) powered devices

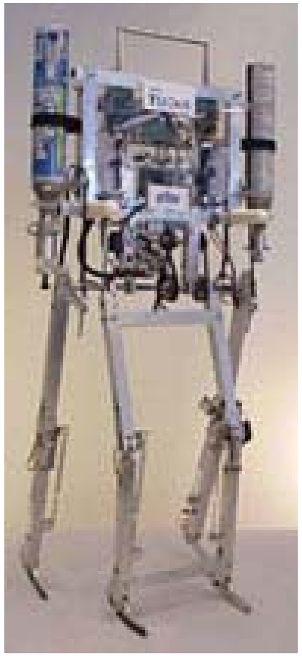


1995

2001



2002



2003

?

robust 3D
stopping
turning
etc...

Van der Linde, Frankenhuyzen,
Wisse, Schwab, Hobbelen



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# A safe manipulator

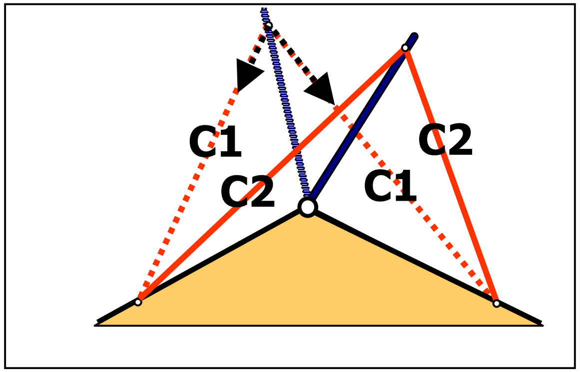
**Problem:**

Arm movement in audience

**Solution:**

Passive compliant motion

**human movement control**
**Lambda model (Feldman)**



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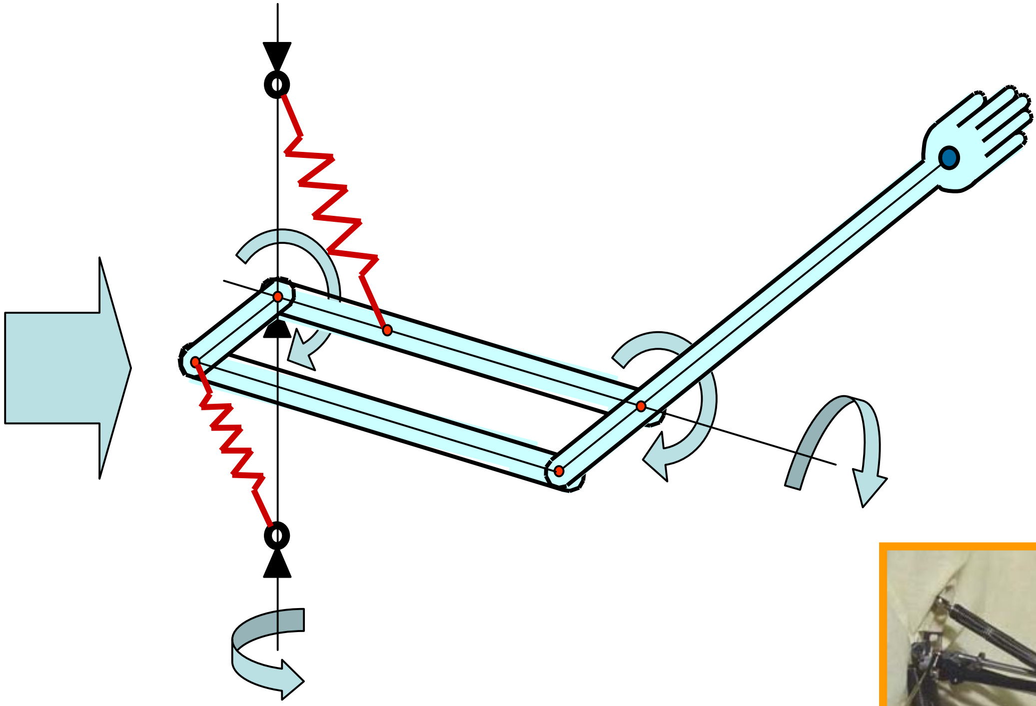
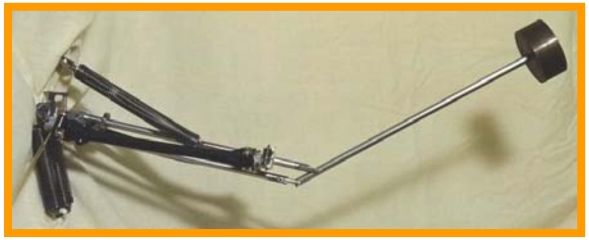
# A safe manipulator

4 DOF Gravity compensation mechanism of hand mass



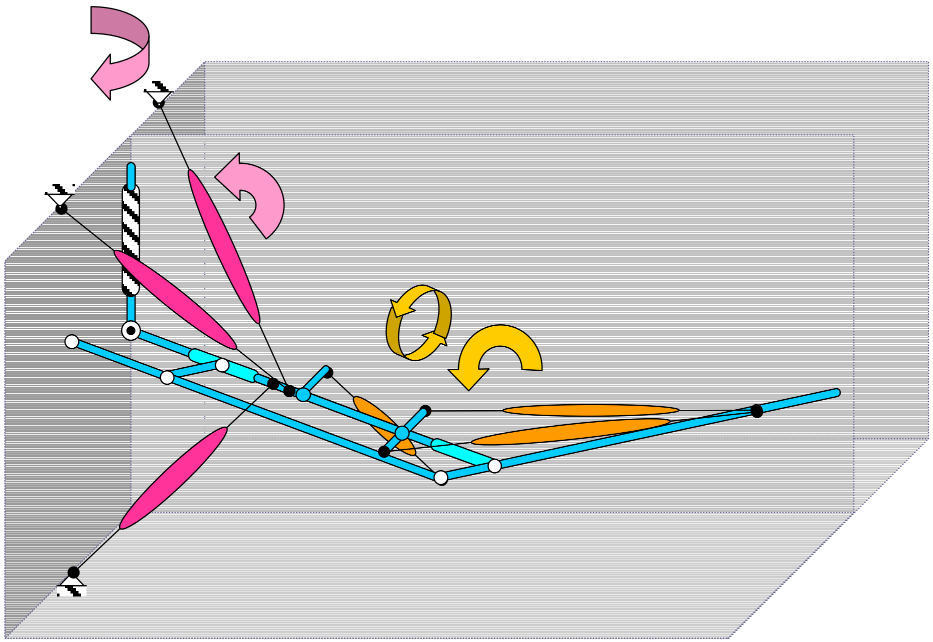
[Herder & Tuijthof, 1998]

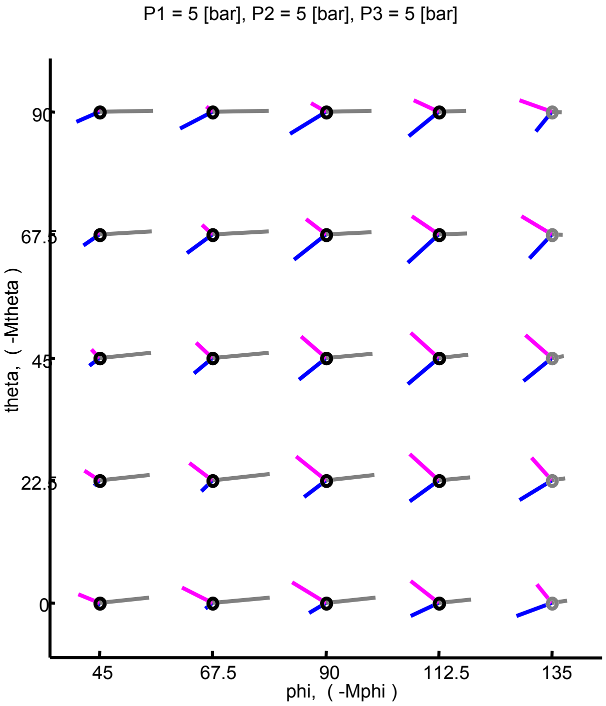
preloaded springs



# A safe manipulator

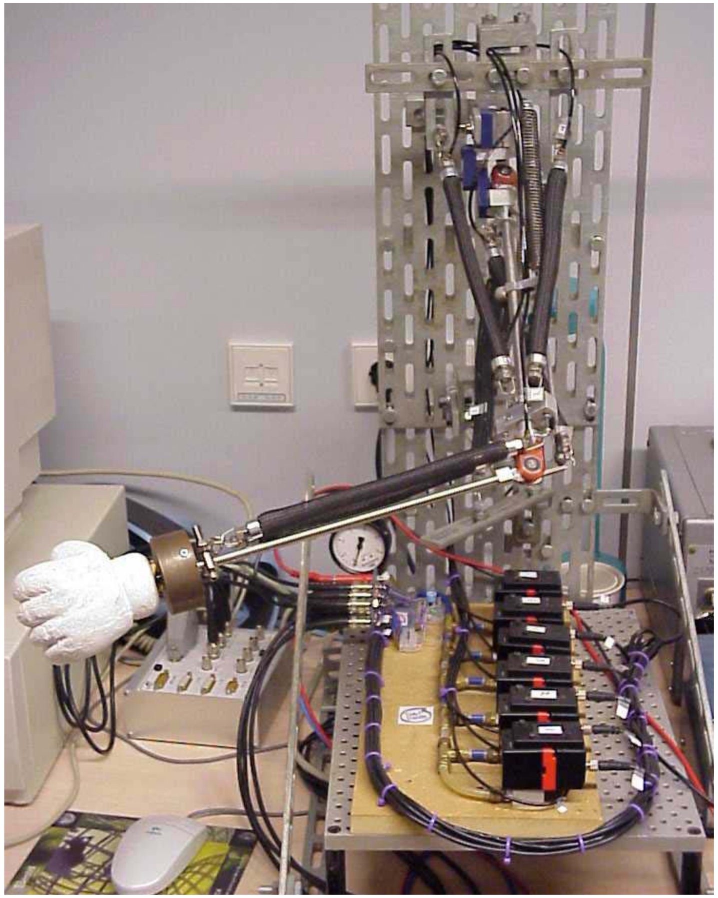
## 6 DOF passive compliant activation

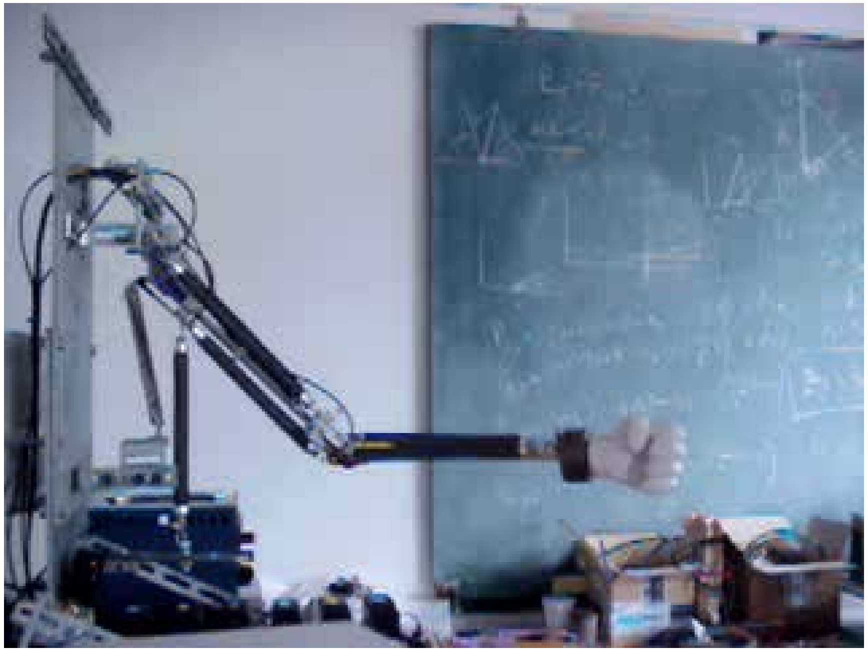





Optimisation of muscle configuration

# A safe manipulator



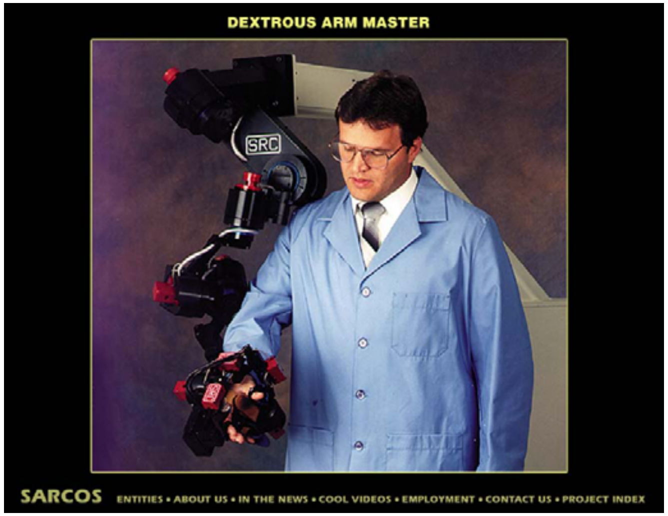


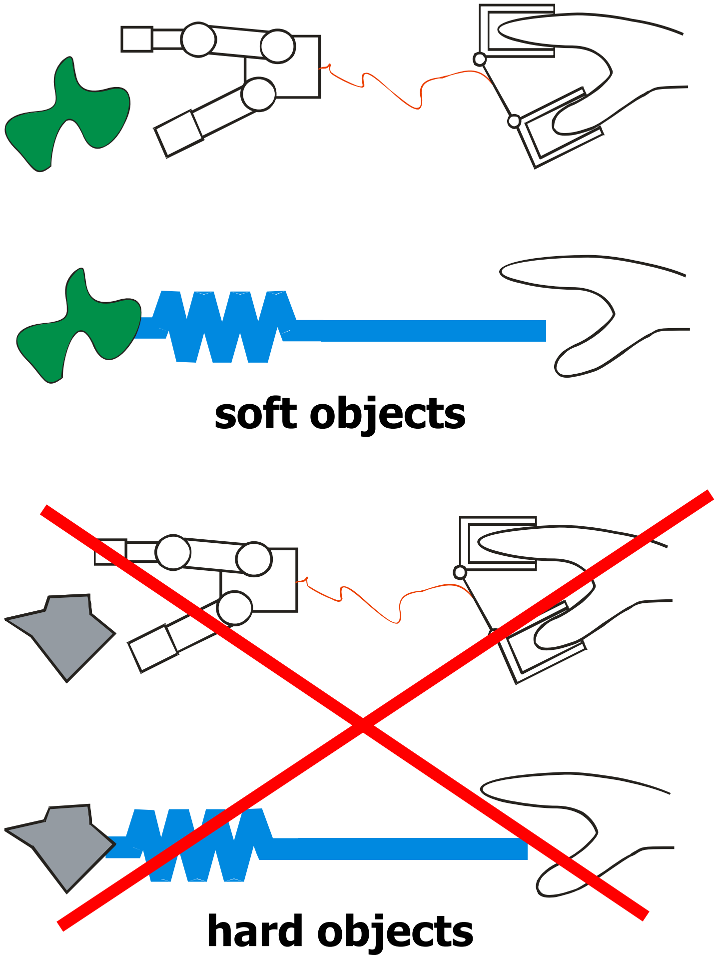
**To be solved:**
dynamic position control

# Biocompatible grasping

**Problem:**

Instabilities during hard contact
(e.g. hammer effect)



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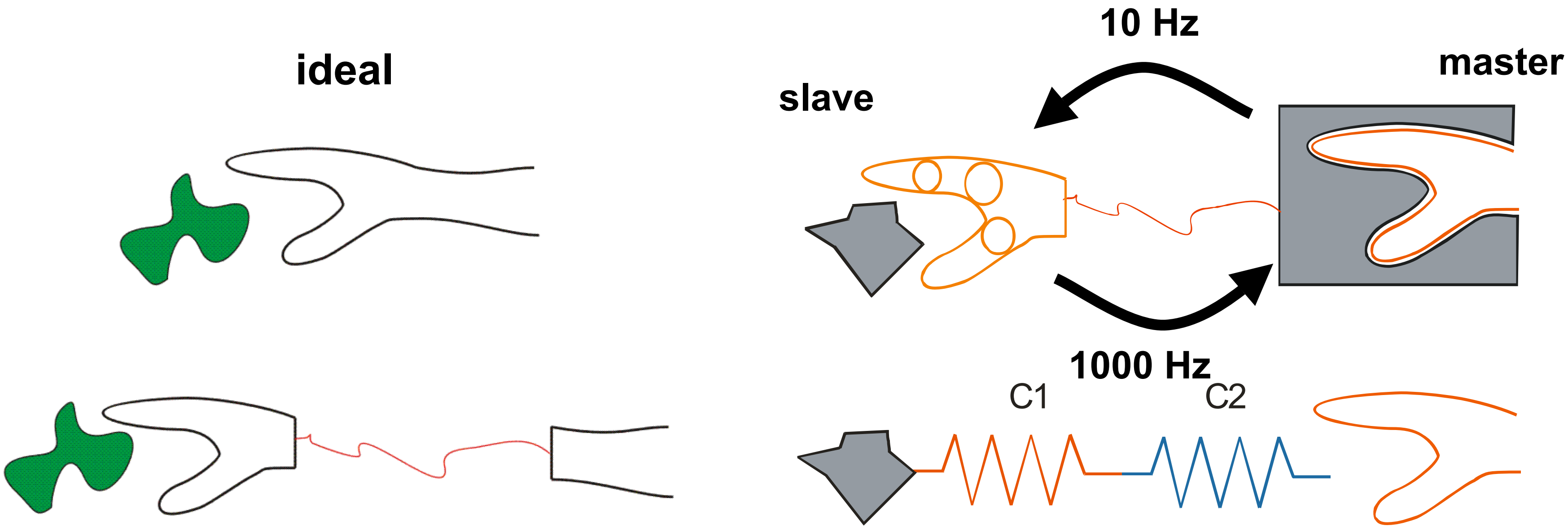
# Biocompatible grasping

**Solution:**

asymmetric teleoperation force feedback control approach



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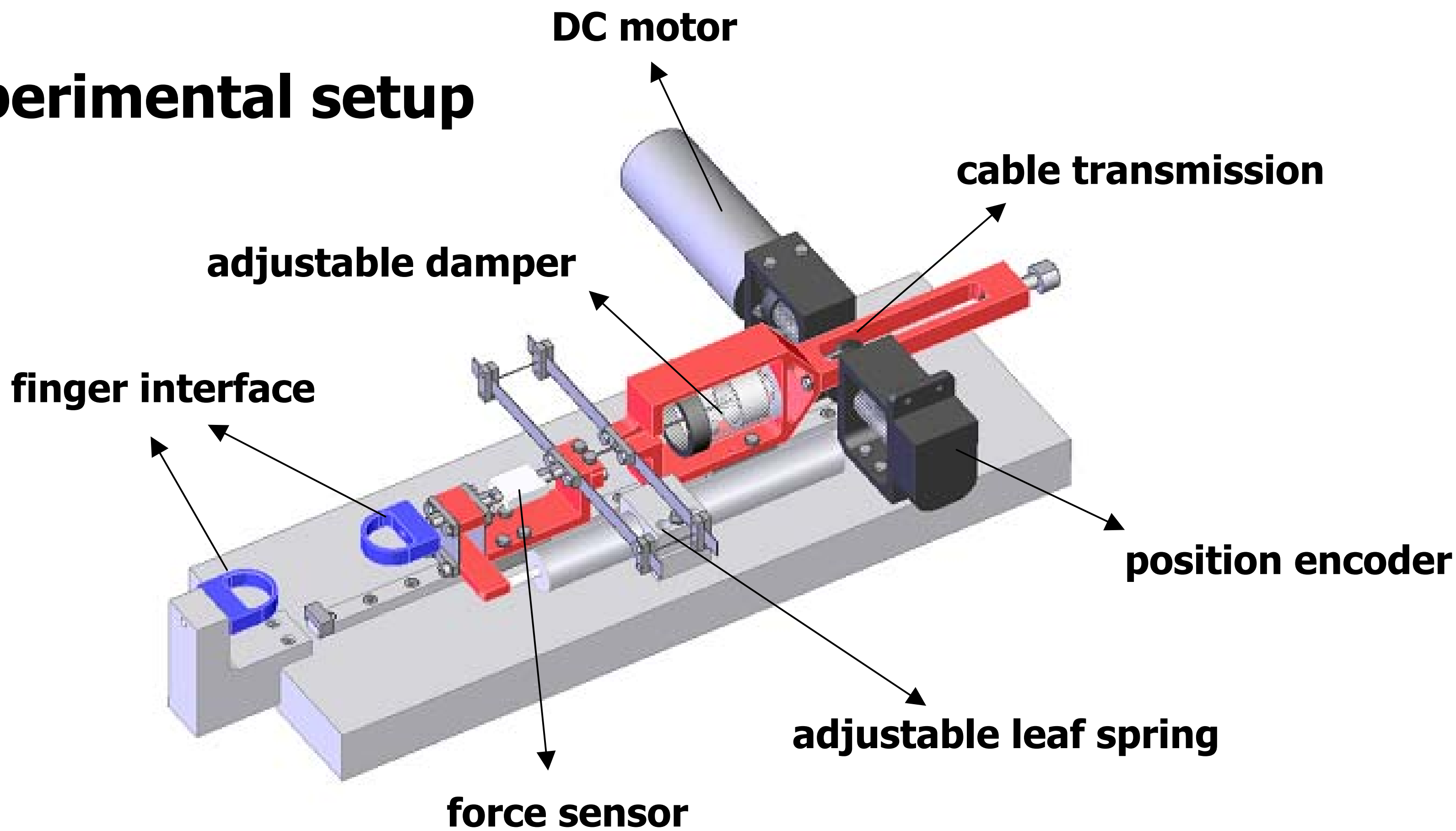
# Biocompatible grasping

## Experimental setup



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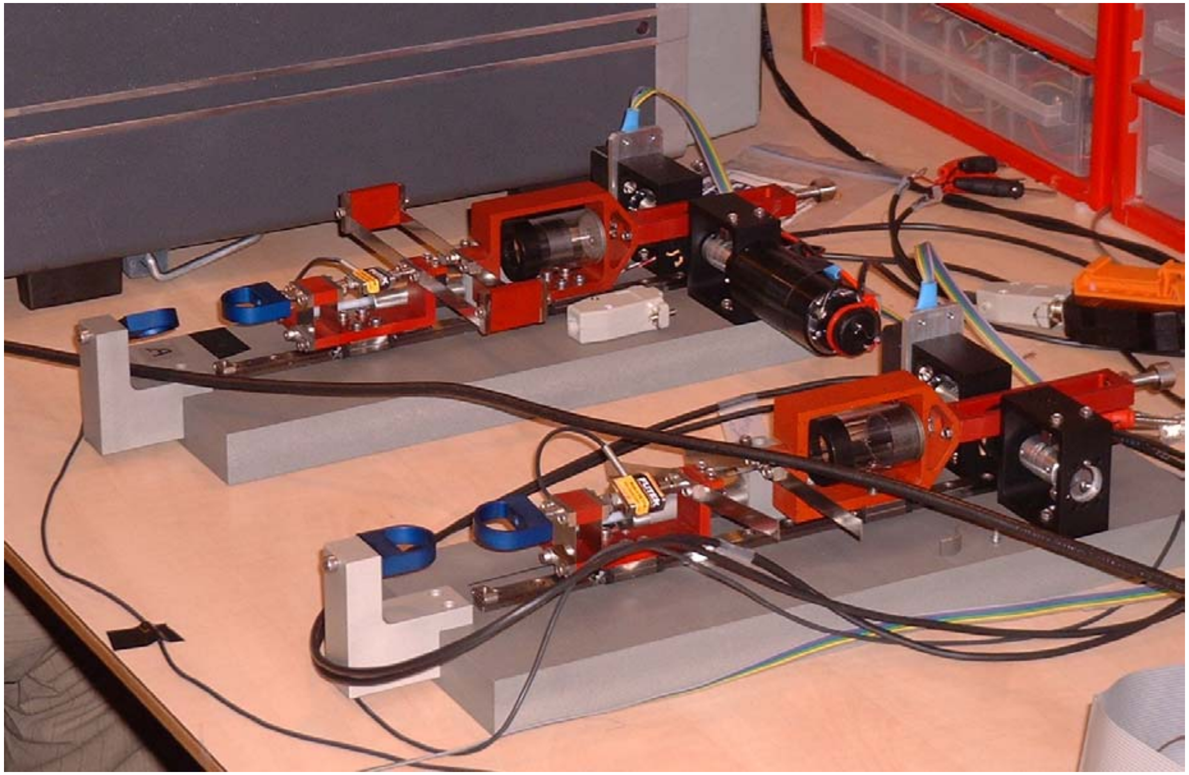
# Biocompatible grasping



stable for hard objects



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# Conclusion

*In biological systems a plethora of control mechanisms seem to be present on different different functional levels, some of which are are active, some of which are passive. Being inspired by these mechanisms has resulted in biorobotic solutions that are* ***simple, adaptive, stable & safe*****.**



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# The 21st century ?

**Åström [2004]**

*Control engineering has a soul but no body*

**Van der Linde [2004]**

*Biorobotics has a body but needs more soul*