Elastic Bodyware for Bio-Inspired Humanoids

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Many Thanks To

BioRob/BioRobAssist

S. Kohlbrecher, J. Kunz, T. Lens, D. Thomas, S. Kurowski

BioBiped

K. Radkhah, D. Scholz, S. Kurowski

and **Andre Seyfarth's Group**: C. Maufroy, M. Maus, A. Seyfarth

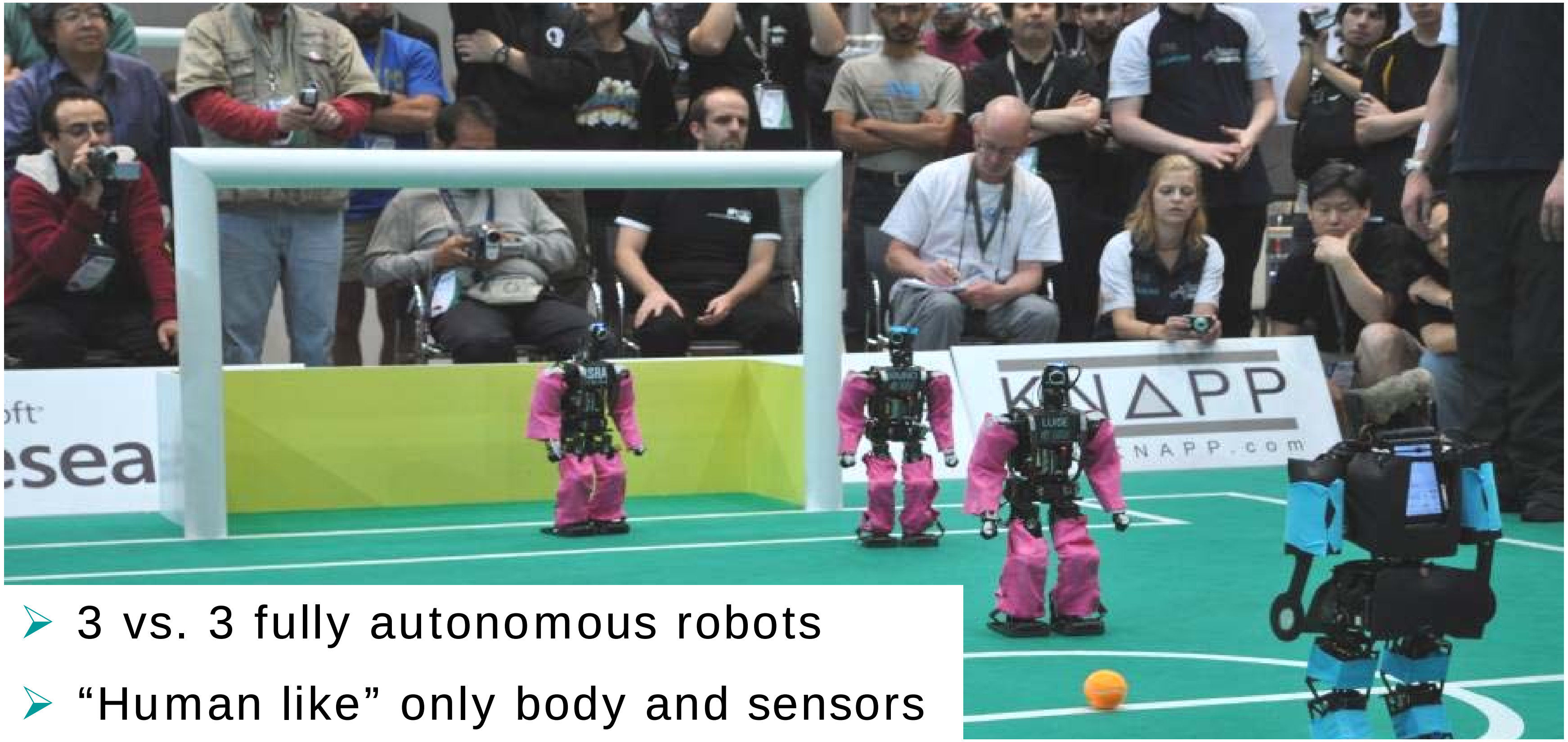
Prologue

We also have extensive experience in conventionally actuated autonomous humanoid robots.

Our investigations on new humanoid bodies are also grounded on this.

RoboCup Humanoid KidSize League

www.dribblers.de

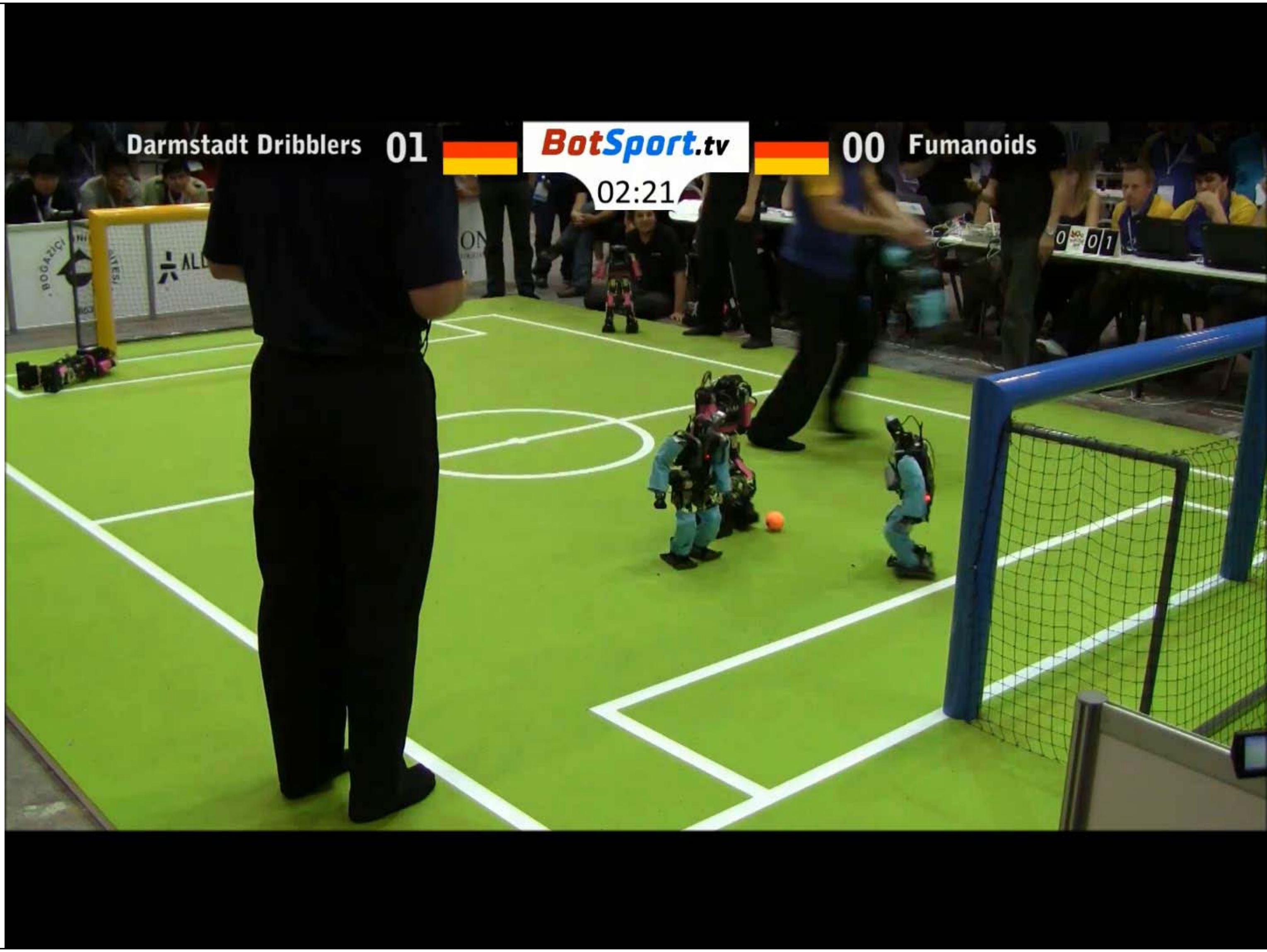


- 3 vs. 3 fully autonomous robots
- “Human like” only body and sensors
- Vision as only external sensor (with field of view limited to 180°)
- Foot area restricted by height of robot and of center of mass

Video of monitoring, analysis and debugging abilities for complex autonomous robots:
http://www.youtube.com/watch?v=8uZJqi_vx1Q

RoboCup Humanoid KidSize League

http://www.youtube.com/watch?v=C1jxfMJsFPU



Elastic Bodyware for Bio-Inspired Humanoids

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Motivation: ASIMO Jogging

Motivation: Human Jogging

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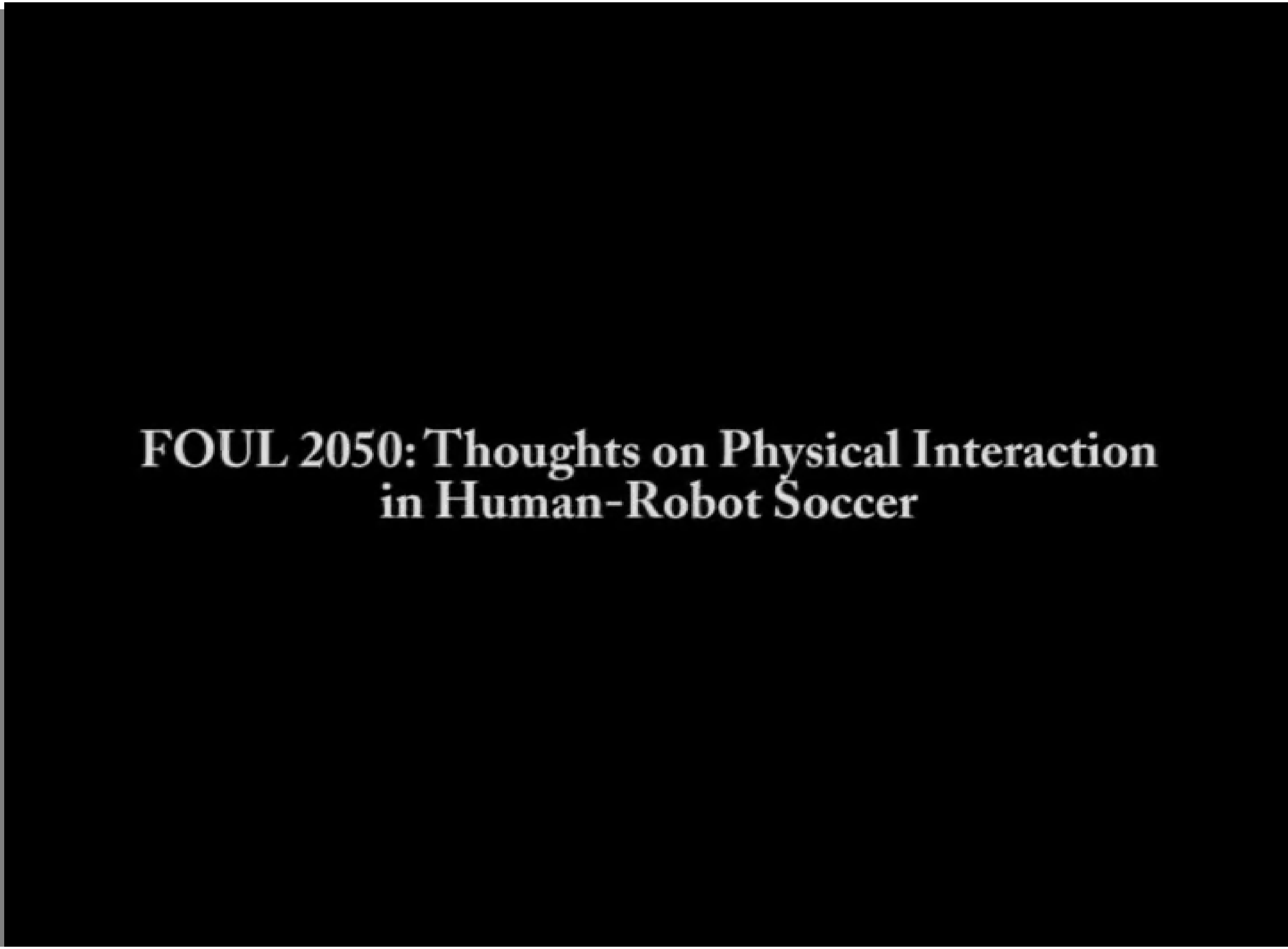
Kicking a Ball (DLR, 2007)

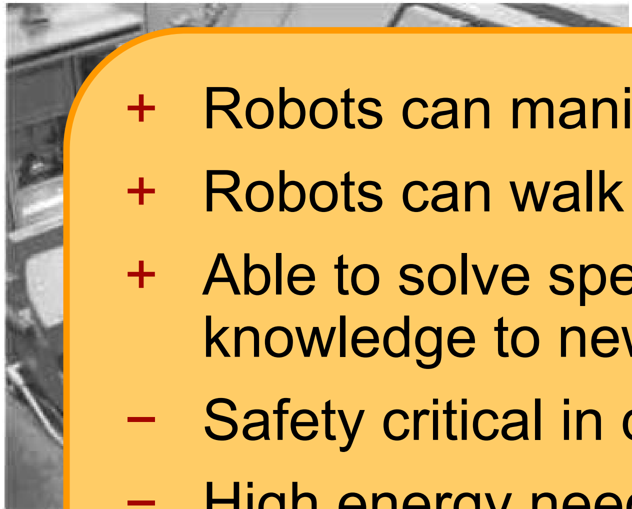
S. Haddadin et al./DLR, IEEE IROS 2007



Benchmark for
Versatile Locomotion, Perception, Control, Cognition

FIFA WorldCup 1974

50 Years of Robotics



- \+ Robots can manipulate (− but not grasp nor throw human like)
- \+ Robots can walk (− but neither balance nor run human like)
- \+ Able to solve specific tasks (− but unable to transfer skills and knowledge to new tasks)
- − Safety critical in direct vicinity to humans
- − High energy needs

…

→ Elastic bodyware is key for a big leap!

- Kinematic chains of rigid joints and links
- Mechanical elasticity considered harmful!
- Robots designed from largely independent building blocks which are sensors, acutators, computers, SW, …

SoA of Robot Motion

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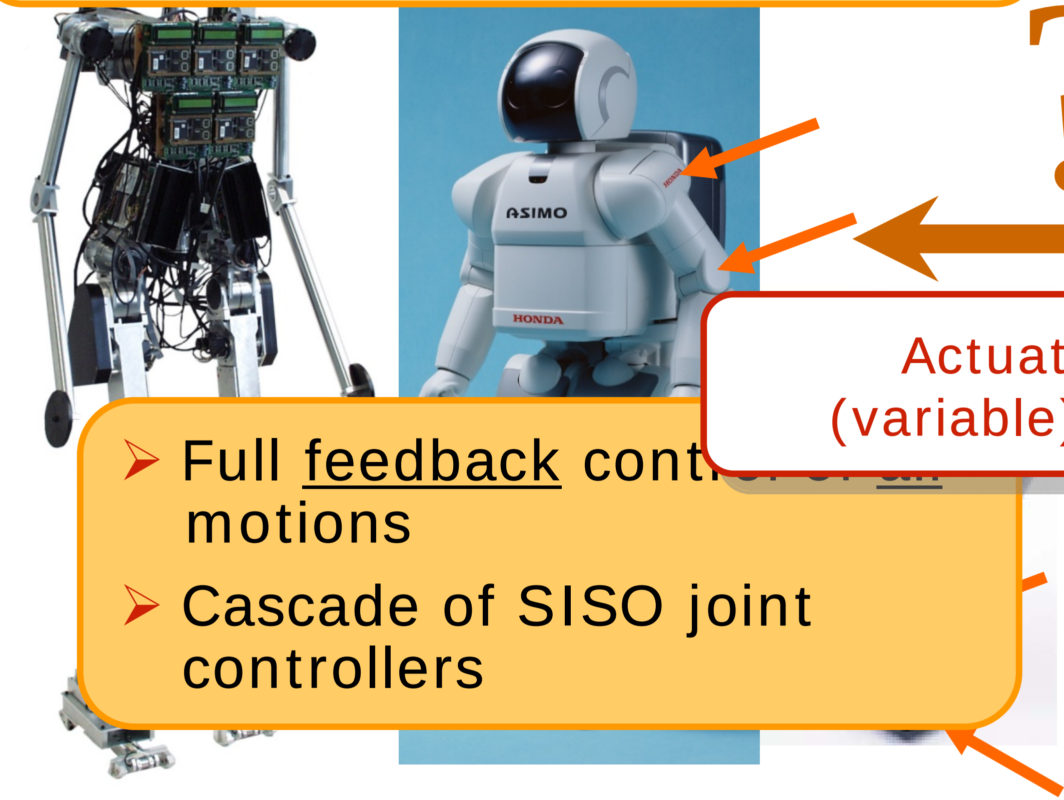
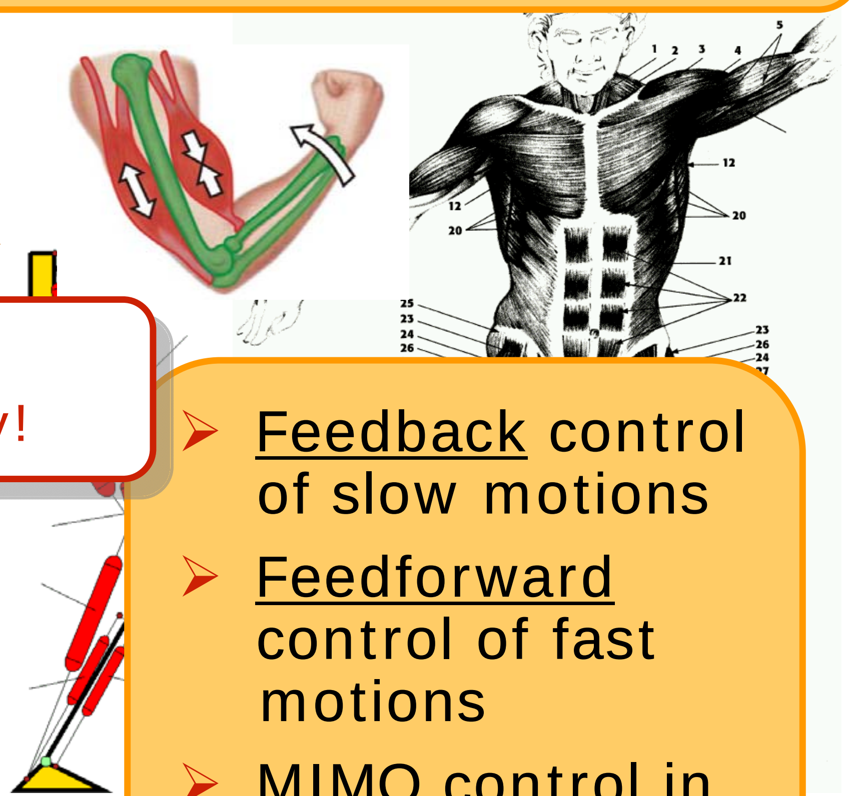
Rigid robotic manipulator arms and legs (= tailored rigid arms) !

Elastic, highly redundant, dynamic locomotor system!



?

Actuation with (variable) elasticity!



- Full feedback control of all motions
- Cascade of SISO joint controllers

- Feedback control of slow motions
- Feedforward control of fast motions
- MIMO control in task space

Johnnie (TU ASIMO (Honda) QRIO (Sony)

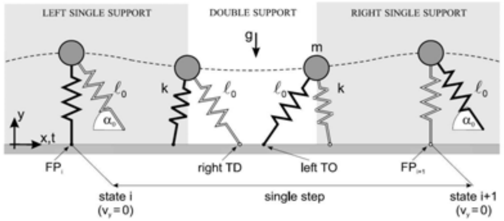
- powerful, rigid, rotary electric actuators
- 1 motor per joint

- redundant, "s…
- controlled by central nervous system
- (partly) self adapting and self stabilizing

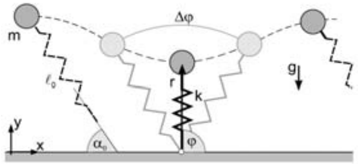
Example: Robotic Legs

Versatile limb performance in task space

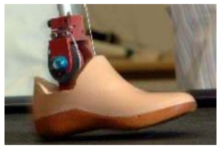
Walking



Running



Standing



- 1-segmented telescopic legs
- Walking, Running: Yes
- Standing: No

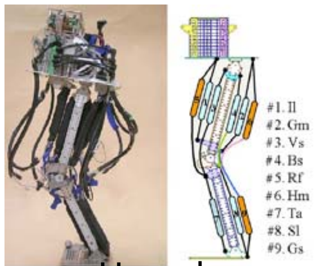
Raibert, MIT (1992)

DLR Biped

Virtual compliance (F/M sensing, impedance control):
- Performance limited by bandwidth of sensors and strength motors
- Walking, Standing: Yes
- Running: No

(New) Compliant actuators: E.g.
- Electroactive polymers: yet too weak
- Pneumatic actuators:
  - High forces possible, very robust, but compressibility of air make position accuracy and velocity control difficult
  - Low mobility: onboard compressor or cable supply
- Fluidic / hydraulic / ... elastic actuators

Lucy (VU Brussels)

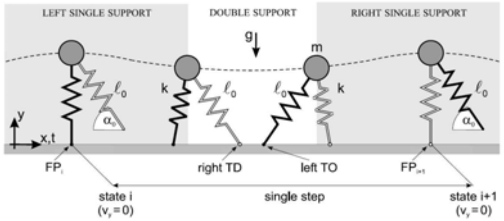


Hosoda (2010)

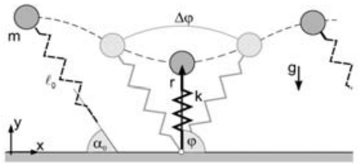
Example: Robotic Legs

Versatile limb performance in task space

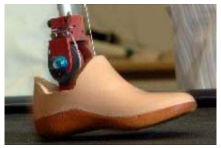
Walking



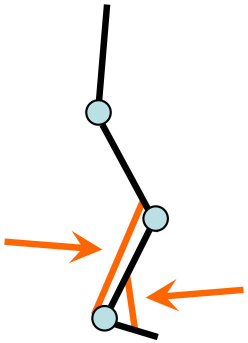
Running

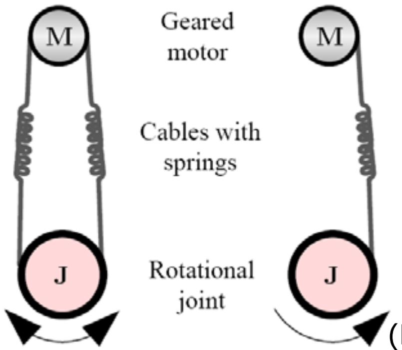


Standing



(ii) “Musculoskeletal SEA”



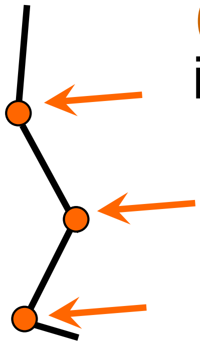


www.biorob.de
www.biobiped.de

(Radkhah/vS, IROS 2011)

Combinations of (rotary) electric actuators with mechanical elasticity

- Conserved energy supports push-off
- Instantaneous reaction to disturbances (safety, robustness)



(i) “Joint SEA” (or variable impedance actuators)

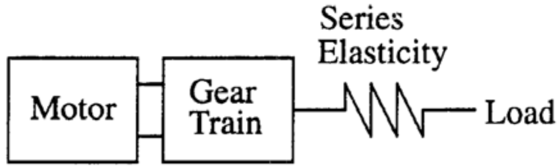


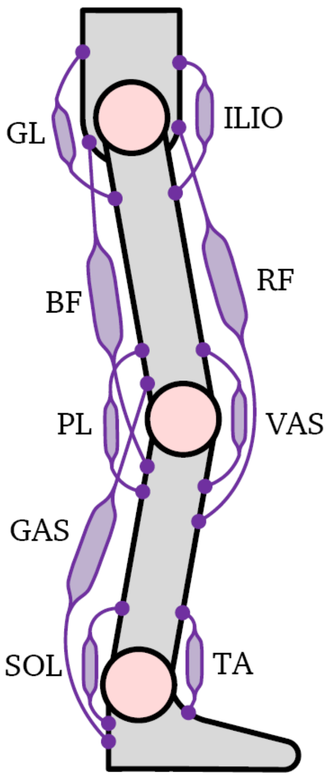
Figure 1: Block Diagram of Series-Elastic Actuator

(Pratt/Williamson, MIT 1995)

- Variable stiffness actuator (DLR, 2007), MACCEPA (VU Brussels), VIACTORS EU-Project (since 2009, Albu-Schäffer/DLR, Bicchi/U Pisa, Lefeber/VU Brussels et al.)
  - Typically 2 electrical actuators per compliant joint

Why “Musculoskeletal SEA”? Roles of Muscles and Tendons

How to Utilize these General Insights for New Robots ?



- Spring-damper properties = analog PD-controllers
- Biarticular muscles mainly transfer energy from proximal to distal joints and synchronize the motion the leg joints.

  R. Jacobs, M. F. Bobbert, J. G. van Ingen Schenau, “Mechanical output from individual muscles during explosive leg extensions: The role of biarticular muscles,” Journal of Biomechanics, vol. 29, no. 4, pp. 513–523, Apr. 1996
- Monoarticular muscle structures strongly contribute to the task of power generation during jogging.

  L. Grègoire, H. E. Veeger, P. A. Huijing, and G. J. van Ingen Schenau, “Role of mono- and biarticular muscles in explosive movements,” International Journal of Sports Medicine, vol. 5, pp. 301–305, 1984.

- Actuation by muscles ~ approximate feedback linearization for a conventional 2DoF robot arm.

  S. Klug, “Konzepte der Gleichgewichtspunkttheorie zur Regelung und Steuerung elastischer Roboterarme”, PhD Thesis, TU Darmstadt, 2009

BioBiped Project

(since 2009, TU Darmstadt, with A. Seyfarth's Group)

DFG Deutsche Forschungsgemeinschaft

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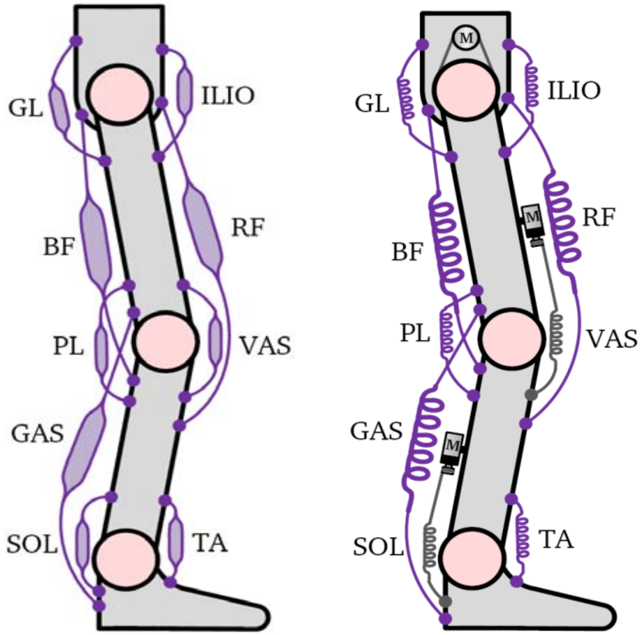
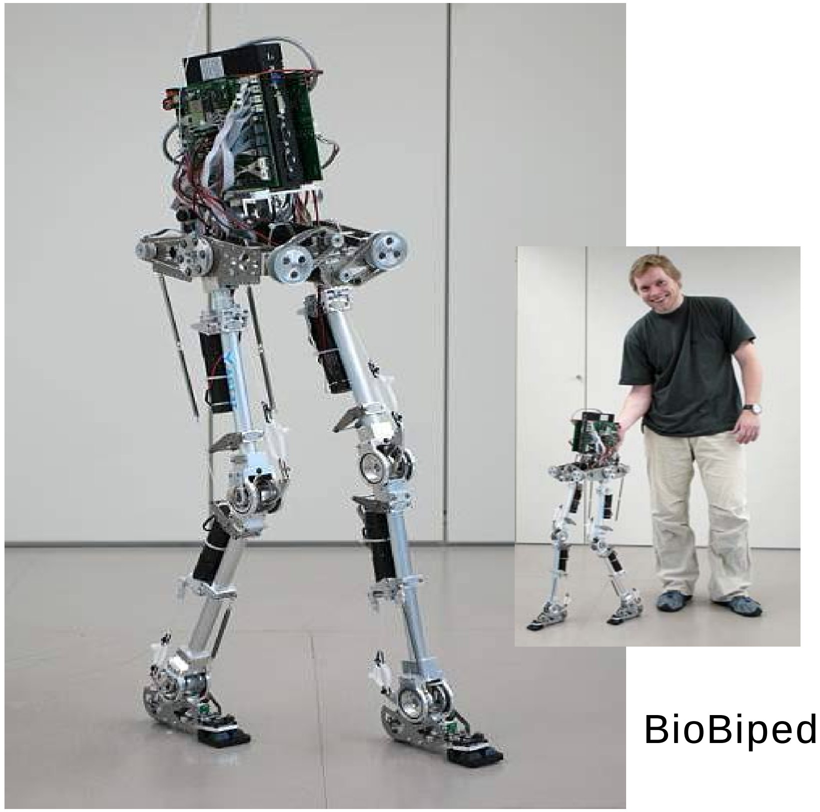
Goal: A biomechanically inspired humanoid robot, capable of

running <u>and</u> walking <u>and</u> standing

including transitions.



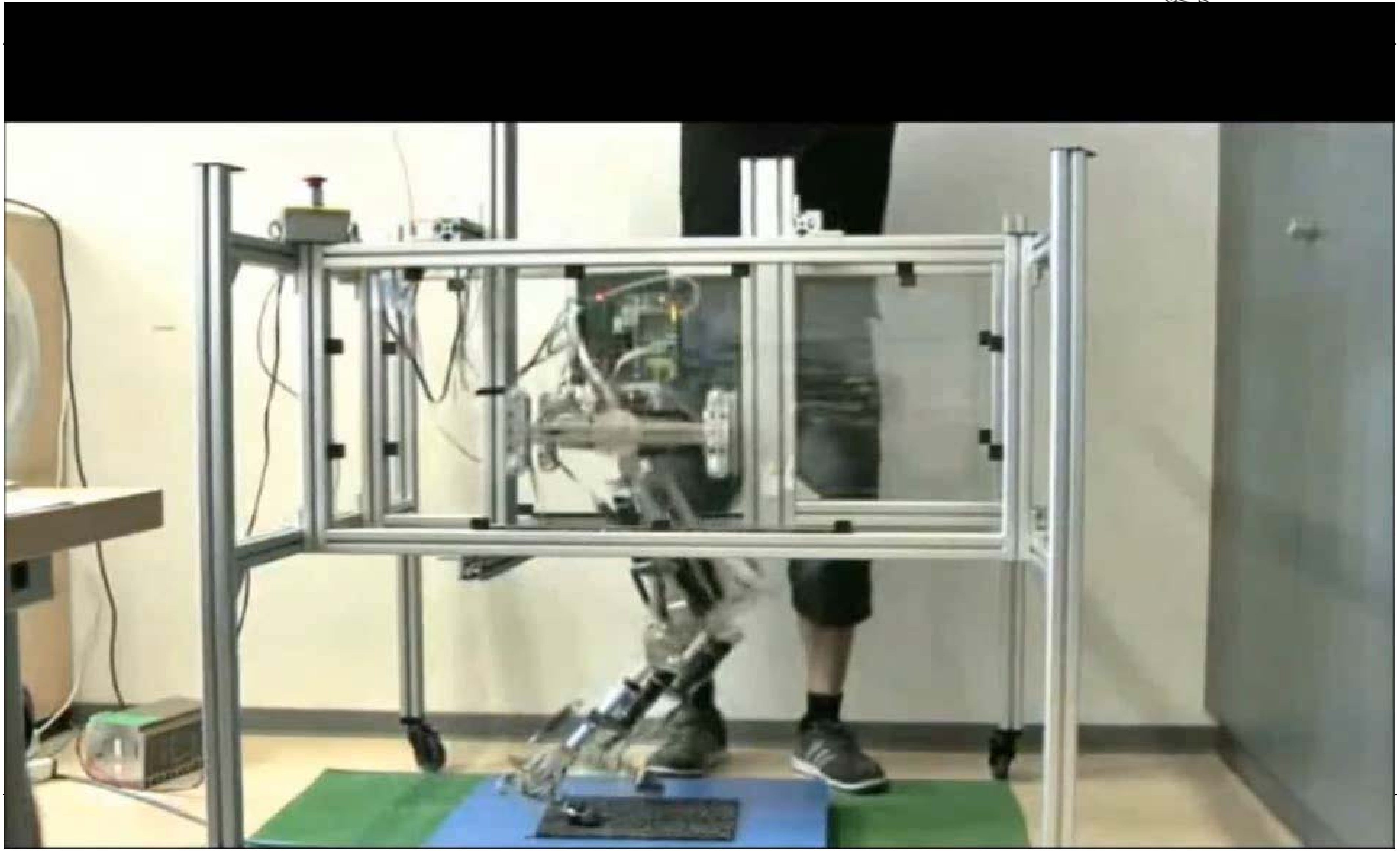


BioBiped1

www.biobiped.de

Experiment: Alternate Hopping

www.biobiped.de



BioRob™ Project Approach

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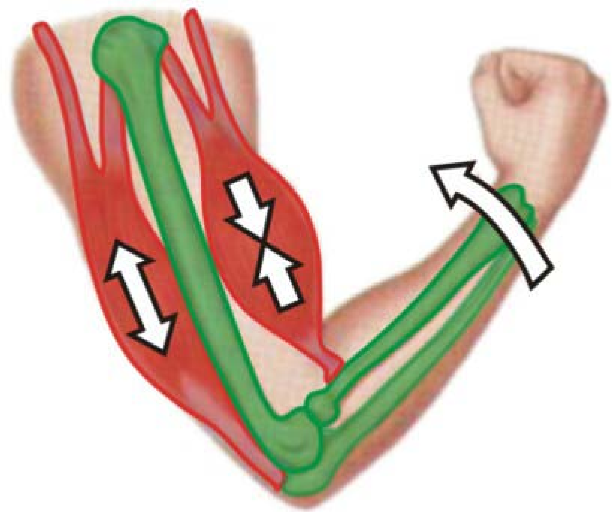
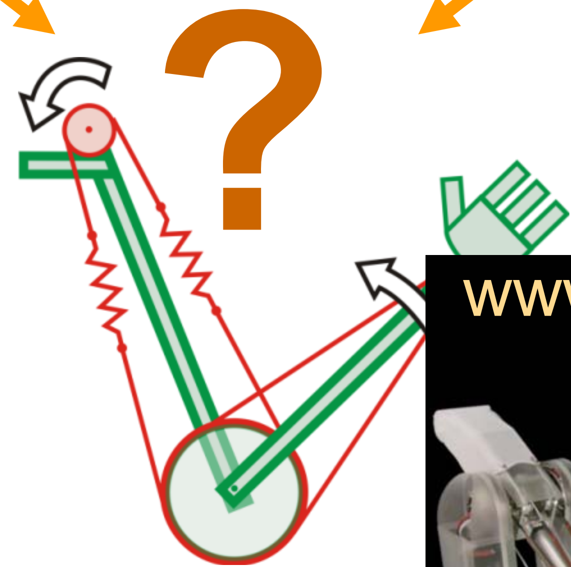
Industrial Robot

Fig.: KUKA

Biological Manipulator



BioRob-Arm



Joint project with
B. Möhl (Univ. Saarbrücken),
TETRA GmbH (Ilmenau)

Elasticity and Vibrations

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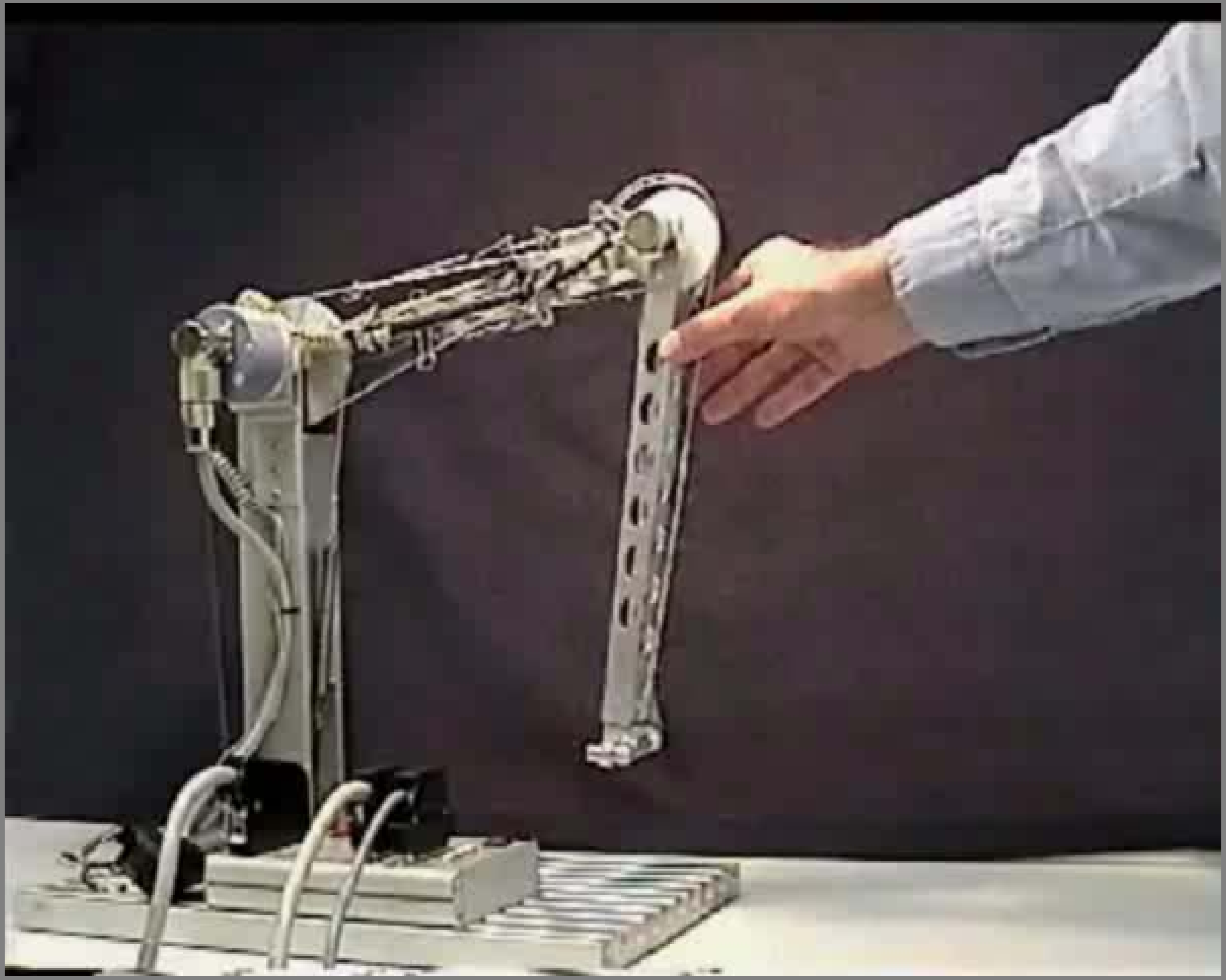


Actuated motion (2 DoF model) (B. Möhl)

Vibration Damping

Actuated motion (2 DoF model) (B. Möhl)

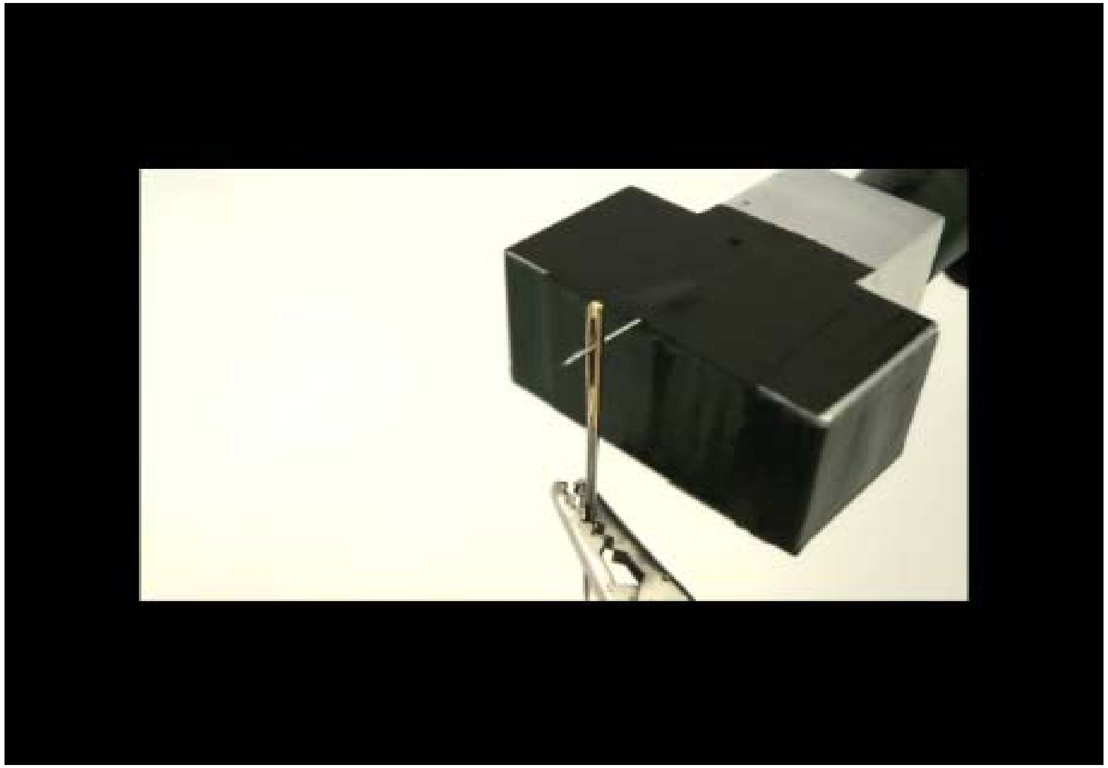
Repeatability

2 DoF model

Repeatability

2 DoF model

Repeatability



http://www.youtube.com/biorobde

High Safety in Collisions

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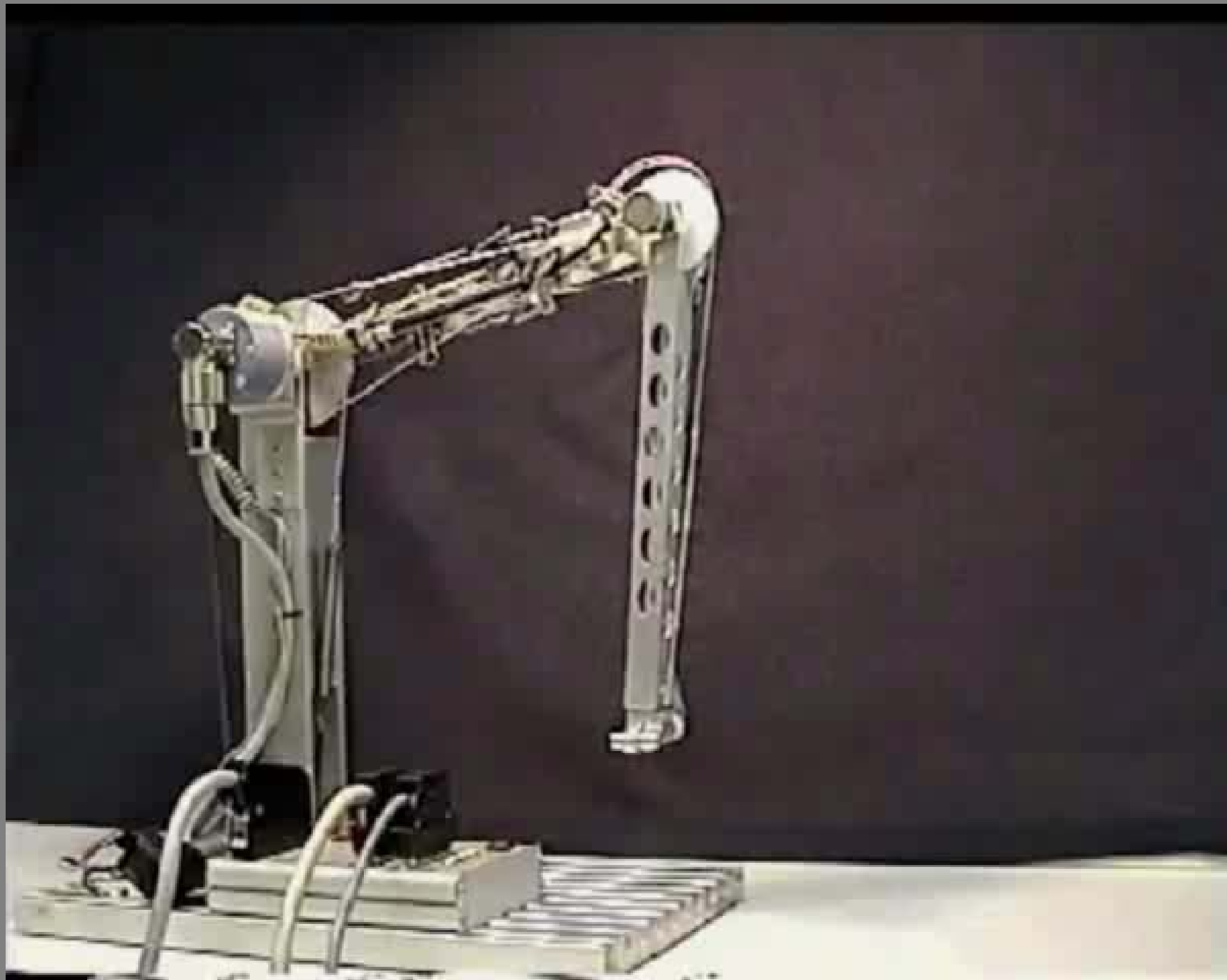


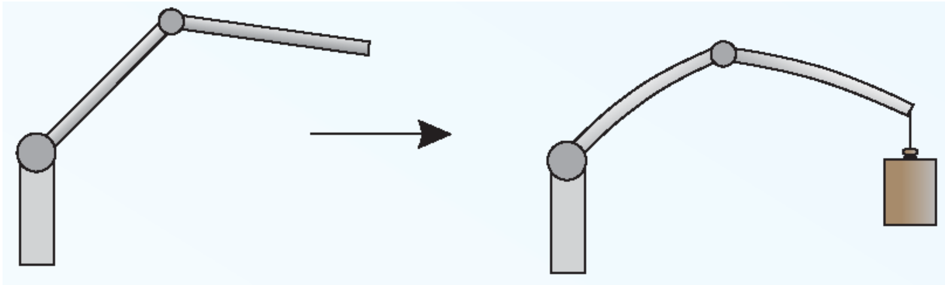
2 DoF model (B. Möhl)

High Safety in Collisions

BioRob-Arm-X4

Why “Musculoskeletal SEA”? Lightweight Design

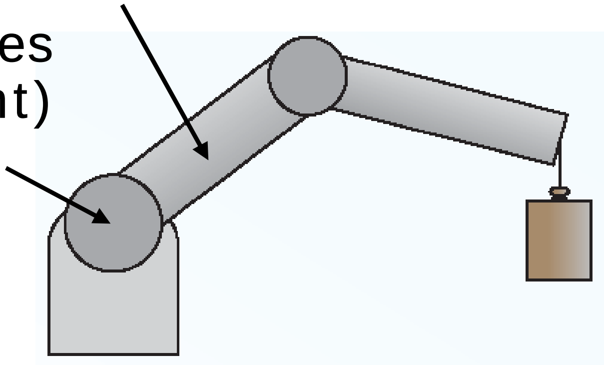
Bending under load



Solution approaches:

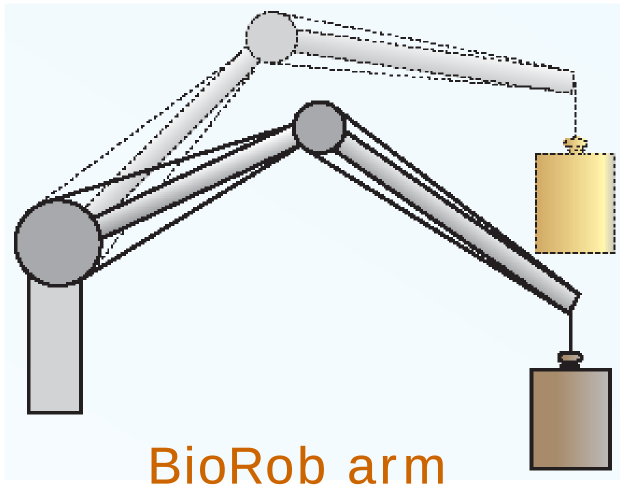
rigid links

rigid drives
(1 per joint)



Rigid series kinematic robot arm

antagonistic elastic actuation



BioRob arm

→ No relief from bending stress when adding elasticity directly in actuated joints!

Teach-In of Pick-and-Place Task

BioRob-Arm-X4

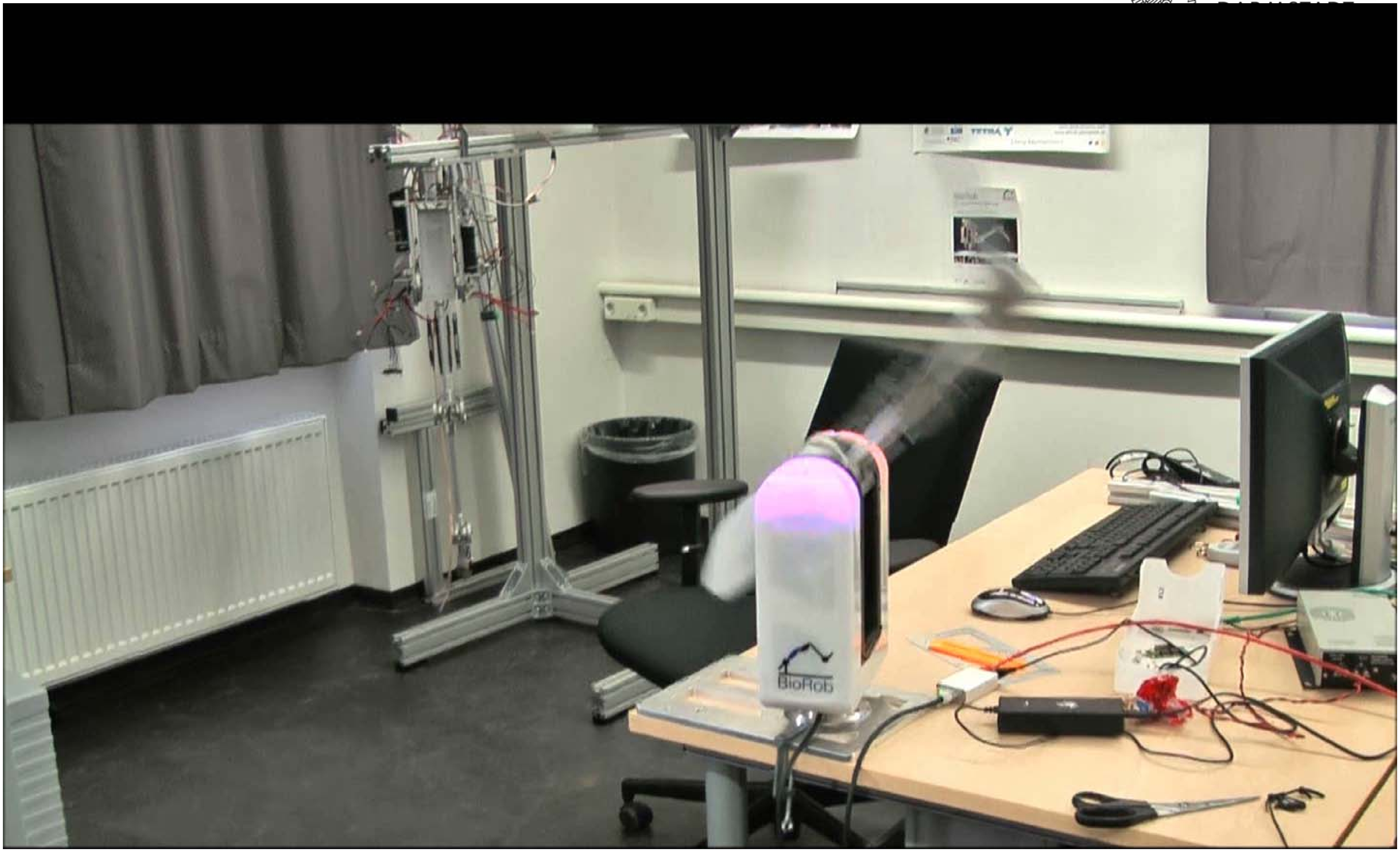
Teach-In of Pick-and-Place Task

http://www.youtube.com/biorobde

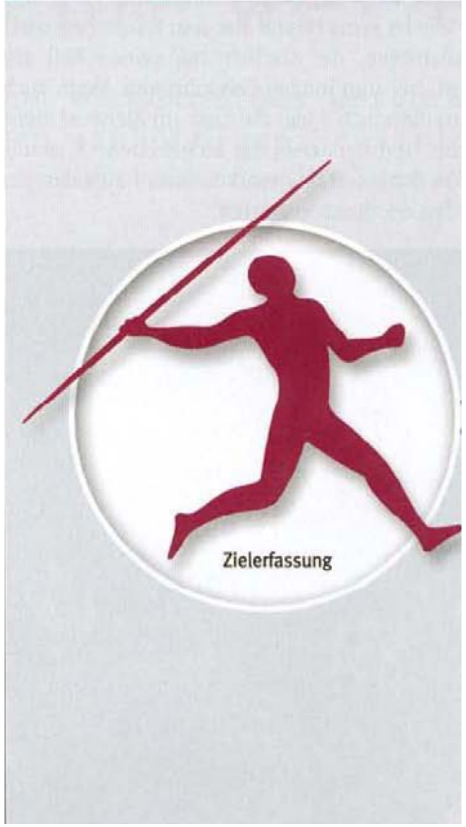
BioRob-Arm-X4

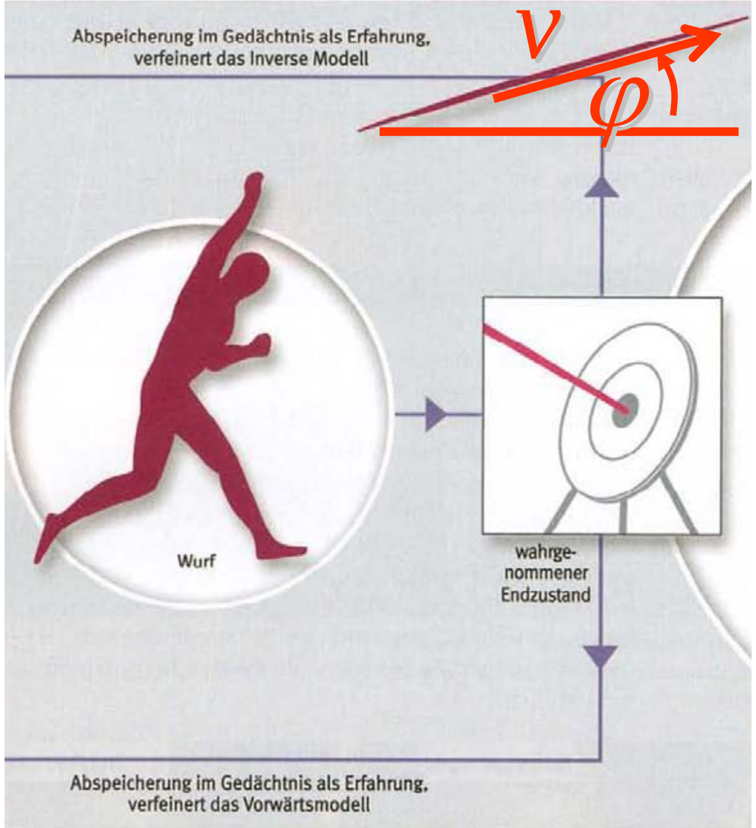
Feedforward Controlled Very Fast Motion

As Needed for Tennis!



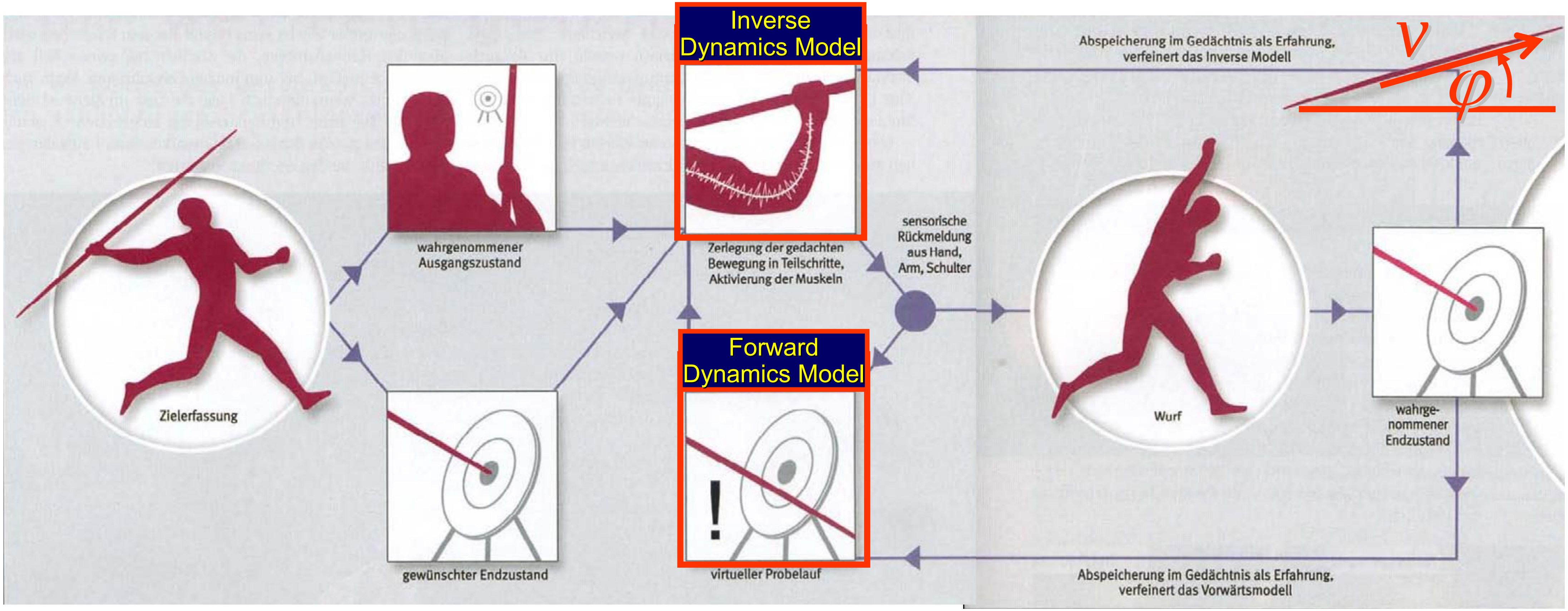
Human Throwing





BdW 8/2007, H. Müller
(Univ. Saarland)

Human Throwing



BdW 8/2007, H. Müller
(Univ. Saarland)

Feedforward Control
Using an Inverse Dynamics Model

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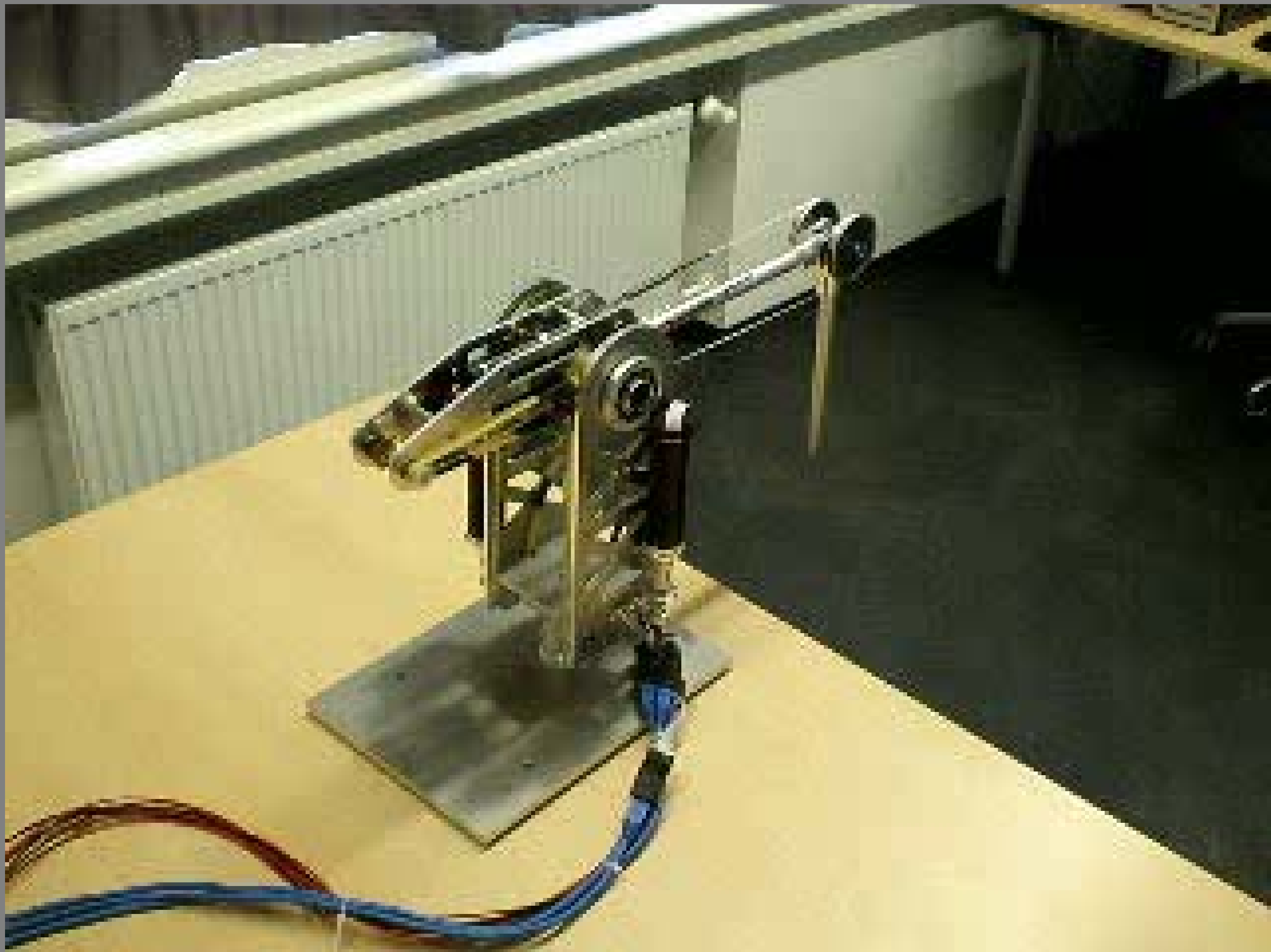
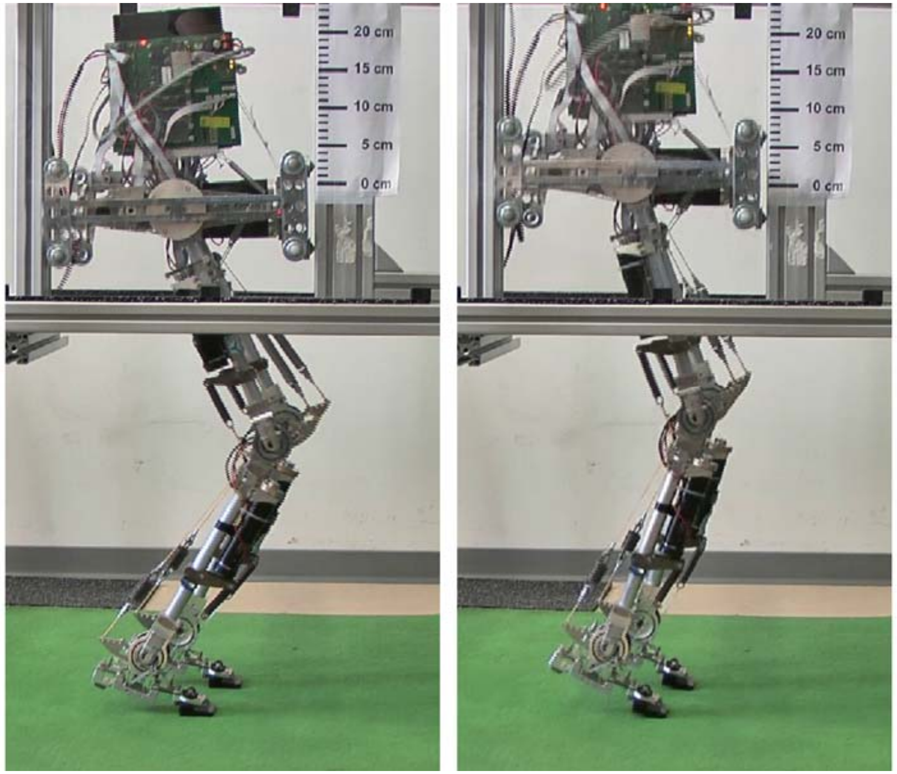
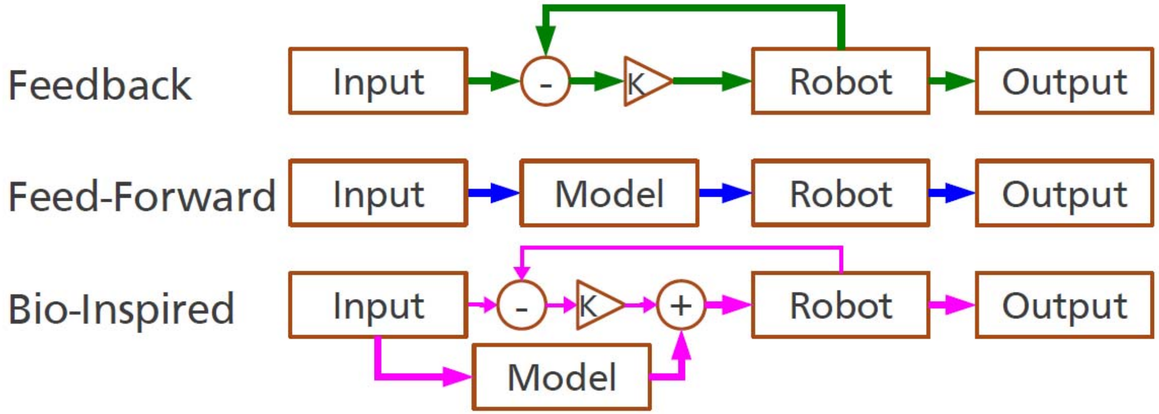


Poster Session, Thursday, Oct 27

D. Scholz, S. Kurowski, K. Radkhah, O. von Stryk:

Bio-Inspired Motion Control of the Musculoskeletal BioBiped1 Robot Based on a Learned Inverse Dynamics Model





Predict – Act – Sense

Conclusions

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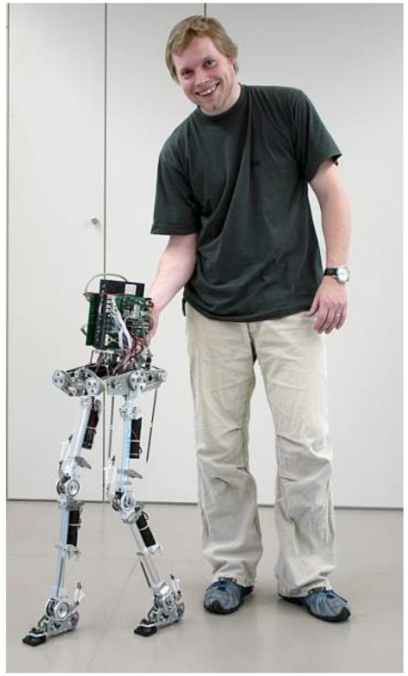
I. Elastic actuation as key to superior, bio-inspired motion performance
   - Variety of elastic actuation approaches
   - Single / multiple joint linkages



II. Morphology in control system (of compliant body) must be investigated
   - New building blocks of (i) elastic actuation and structure, (ii) sensing abilities, (iii) control
   - Sliding modes of feedback and feedforward control

III. Muscles and their control are not only involved in walking, grasping: speech is the most complex motoric act of humans!
   - How does “the body shape the way we think”?

→ Elastic actuation as key to evolution of superior robotic intelligence!