Exoskeletons

Arm Orthoses

Just Herder

Biomechatronics

J.L. Herder PhD

April 11, 2007

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Department of BioMechanical Engineering

Delft University of Technology

Overview

- Exoskeletons
- Casus: Neuromuscular diseases, arm orthosis
- Assignment: make device suitable for the very weak

EXOSKELETON: Dictionary Entry and Meaning

Pronunciation: `eksow'skelitn

WordNet Dictionary

Definition: [n] the exterior protective or supporting structure or shell of many animals (especially invertebrates) including bony or horny parts such as nails or scales or hoofs

See Also: body covering, carapace, cuticle, frame, shell, skeletal system, skeleton, systema skeletale

Webster's 1913 Dictionary

Definition: \Ex`o*skel"e*ton\, n. [Exo- + skeleton] (Anat.) The hardened parts of the external integument of an animal, including hair, feathers, nails, horns, scales, etc.,as well as the armor of armadillos and many reptiles, and the shells or hardened integument of numerous invertebrates; external skeleton; dermoskeleton.

Cockroach

Biology Dictionary

Definition:

1. A skeleton, or support structure, which supports the organism's body from the outside and is formed from the ectoderm. All arthropods (spiders, insects, crustaceans, horseshoe crabs, etc.) possess one. Compare endoskeleton.
2. Any structure that is formed from the ectoderm in vertebrates, like nails, claws, hair, fur, horns, or teeth. (Note: does not include skin, which is an organ.)

Exoskeletons

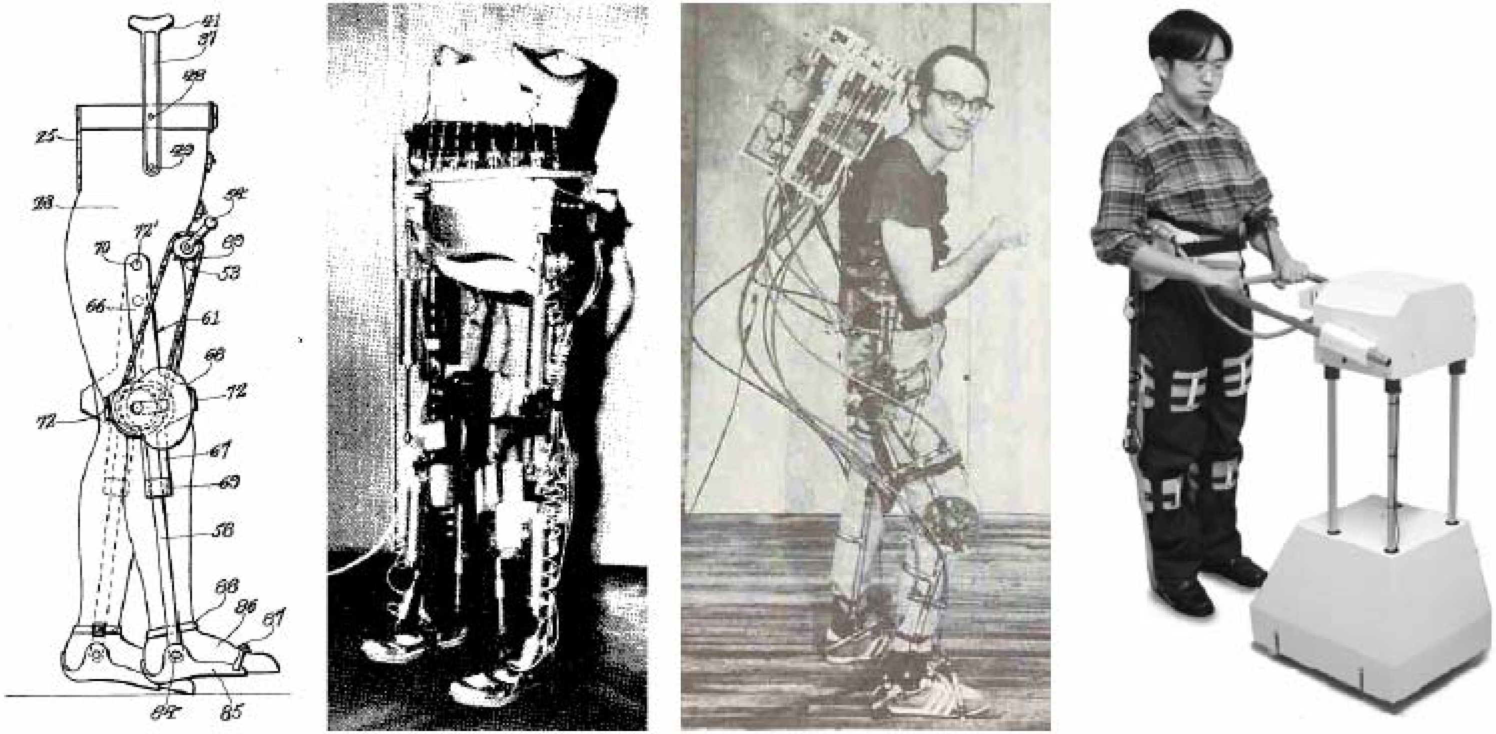


Fig. 5. Cobb's "wind-up" orthosis [ref], Pupin Institute 'complete' exoskeleton [ref], Wisconsin exoskeleton [ref], and Sogang orthosis and walker [ref]. (permission needed)

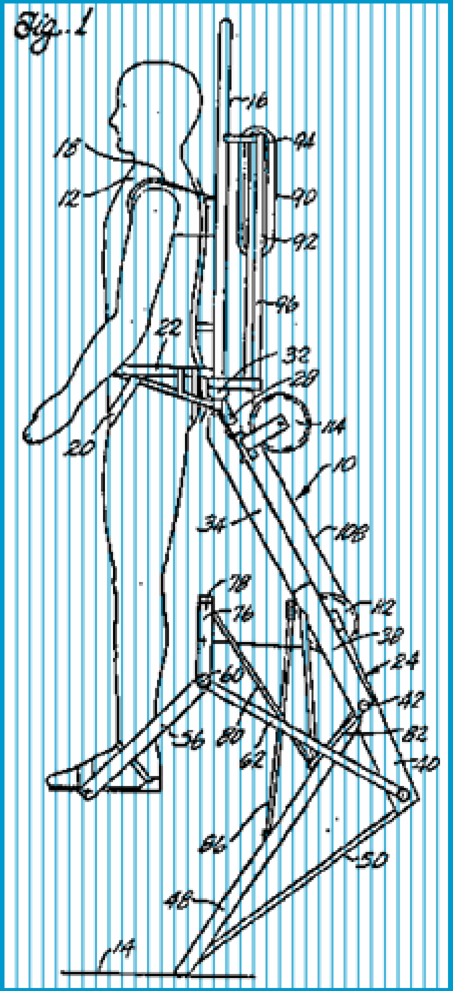
From Aaron Dollar, 2007

Exoskeletons

Fig. 6. MIT active ankle-foot orthosis [ref], Michigan ankle orthoses [ref], Northeastern University knee orthosis [ref], and the weight-bearing control orthosis [ref]. (permission needed)

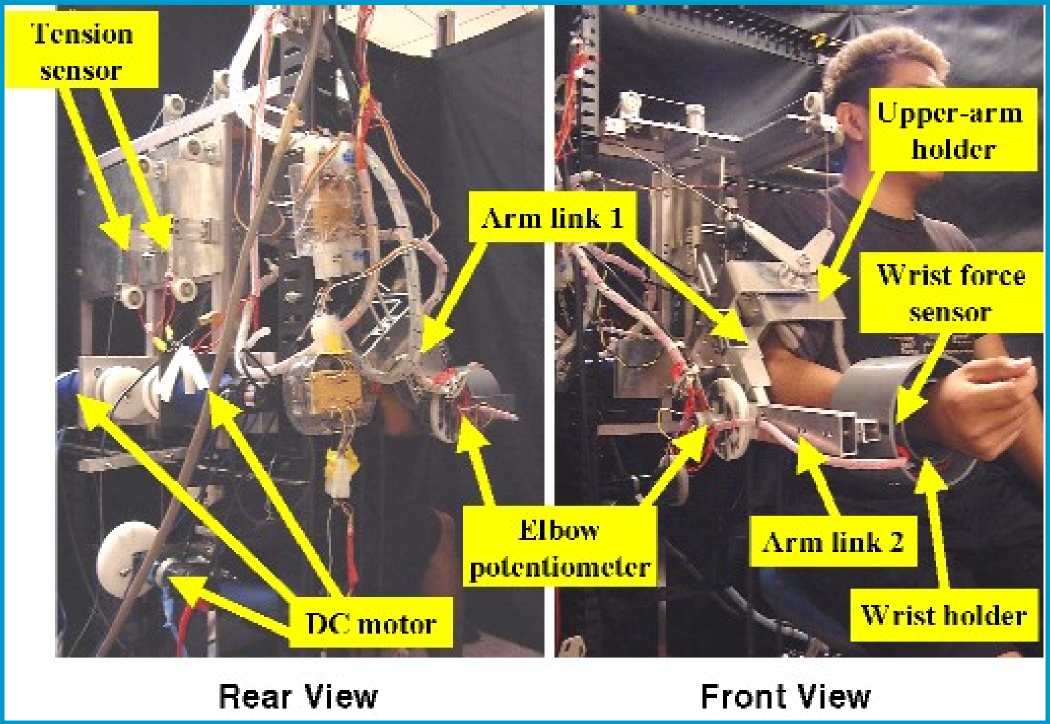
Exoskeletons: lower extremities

SpringWalker



BLEEX Berkeley

Exoskeletons: upper extremities



SAGA

Biorobotics Washington

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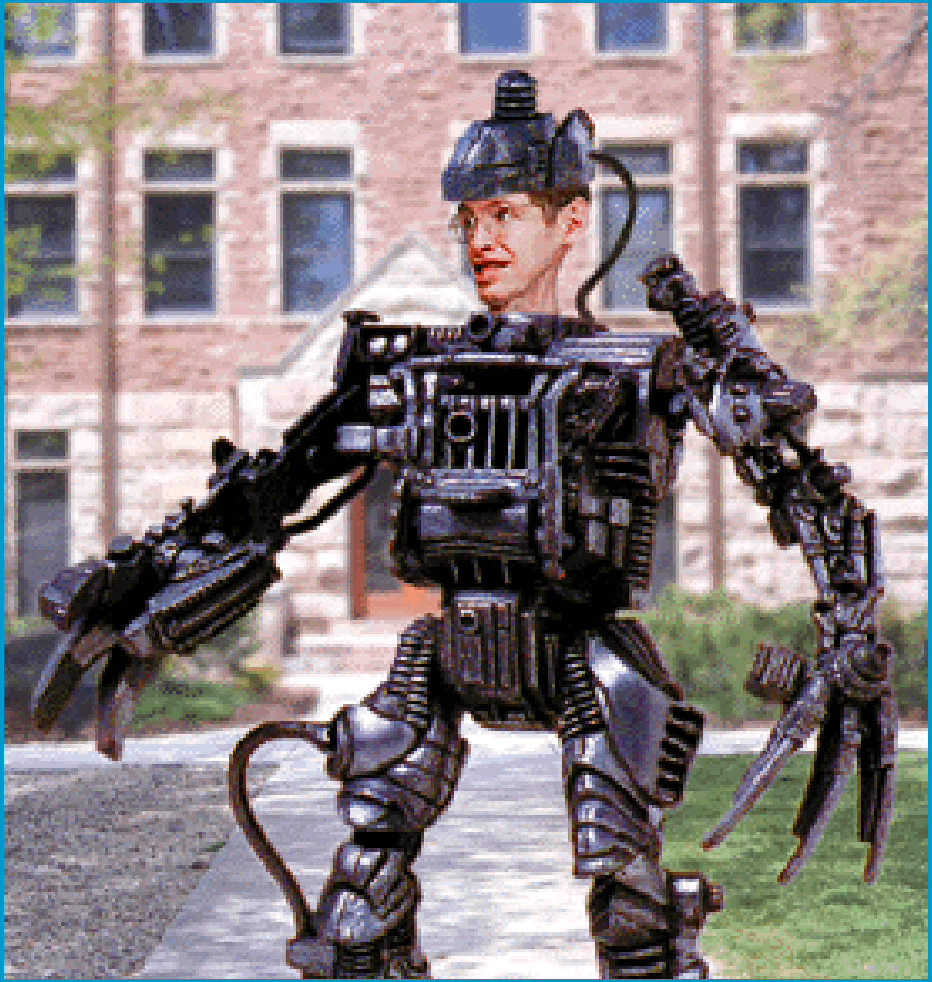
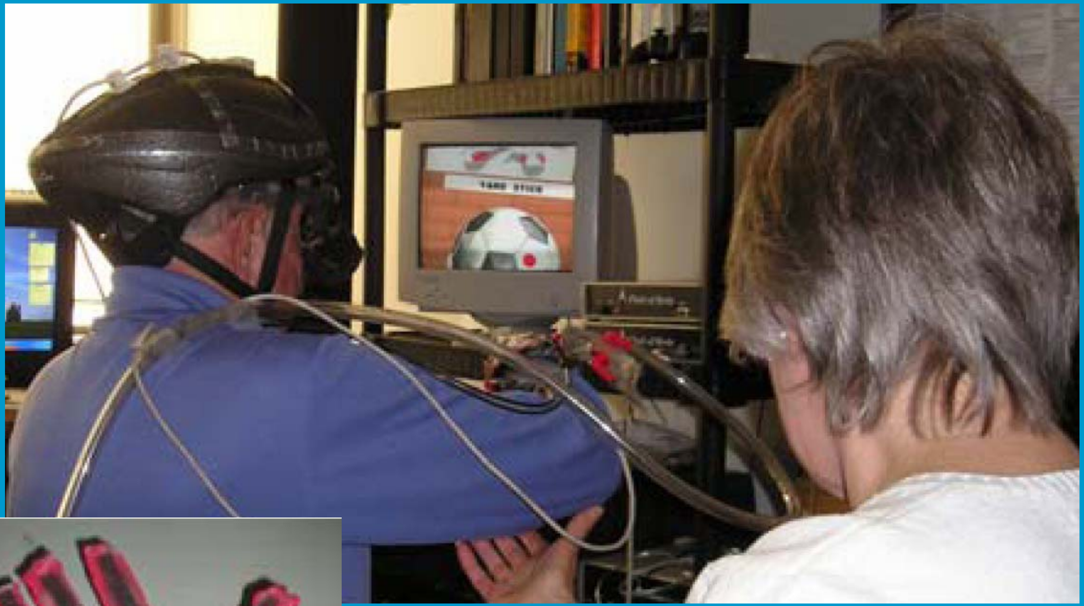
Exoskeletons: all extremities?



Stephen Hawkin?

Pneumatically Controlled Glove to Assist in Grasp Activities



- Extension assist
- VR
- EMG feedback

Tiffany Kline, B.S., Derek Kamper, Ph.D., Brian Schmit, Ph.D.
Rehabilitation Institute Chicago

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Control System for Pneumatically Controlled Glove to Assist in Grasp Activities

Tiffany Kline, RIC and Marquette University, Milwaukee, WI
Derek Kamper, RIC and Northwestern University, Chicago, IL
Brian Schmit, Marquette University, Milwaukee, WI

- Finger extension is the motor function most likely impaired following stroke
- A pneumatic glove was designed to assist finger extension during grasp-and-release training using both real and virtual objects
- The control system regulates pressure in the bladder to control finger joints to desired angles
- Data from a single subject shows improvement in the time required to carry out activities on the Wolf Motor Assessment

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Design of a Robotic Upper Extremity Repetitive Therapy Device

Jiping He, Arizona State University, Tempe, AZ, USA
E. Koeneman, R. Schultz and J. Koeneman, Kinetic Muscles, Tempe, AZ; H Huang, J. Wanberg, D. Herring and T. Sugar, Arizona St. Univ., Tempe, AZ; R. Herman, Banner Good Sam Medical Center, Phoenix, AZ

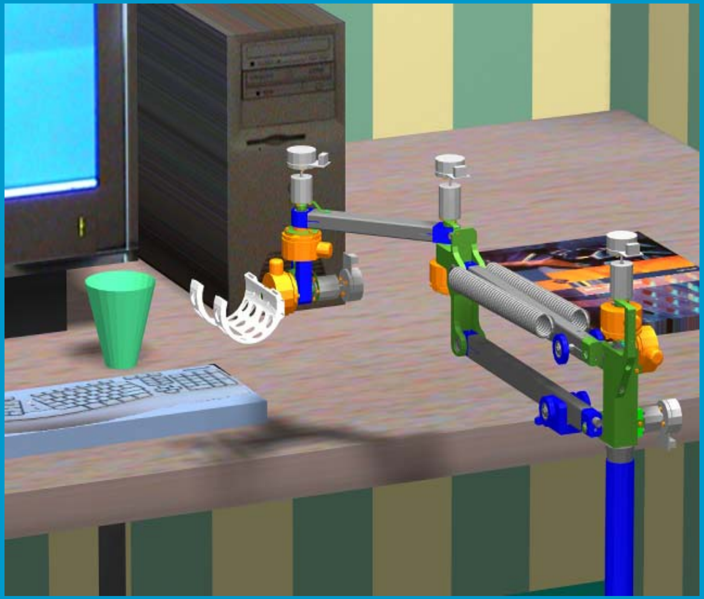
- A wearable (exoskeleton) rehabilitation robot to assist repetitive therapy
- Pneumatic muscles as actuators to reduce weight and provide compliance for safety
- Dynamic model of the robot with arm to assist the design and estimate the voluntary muscle torques
- Four degrees of freedom at shoulder, elbow and wrist
- Can be used for in clinic and in home therapy

Version I of the RUPERT™

a Motorized gravity compensation mechanism used for Active Rehabilitation of upper limbs

Michel van Elk, Bart Driessen, Michiel Dorrepaal,
John van der Werff, Eduard van der Meché, Anton Aulbers,
TNO Science & Industry, Delft, The Netherlands

- Projectname:ACRE(ACtive REhabilitation)
- Our second prototype features gravity compensation using springs and 5 motorized degrees of freedom
- The system provides movement therapy supported by interactive entertaining software
- Evaluations are planned for Q3&4 2005
- The ultimate goal is a motivating training system for home use



The prototype in a virtual 3D environment

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Adjustable Robotic Tendon using a ‘Jack Spring’™

Kevin W. Hollander, Mechanical Engineering, Arizona State University
Thomas G. Sugar, Mechanical Engineering, Arizona State University
Donald E. Herring, Industrial Design, Arizona State University

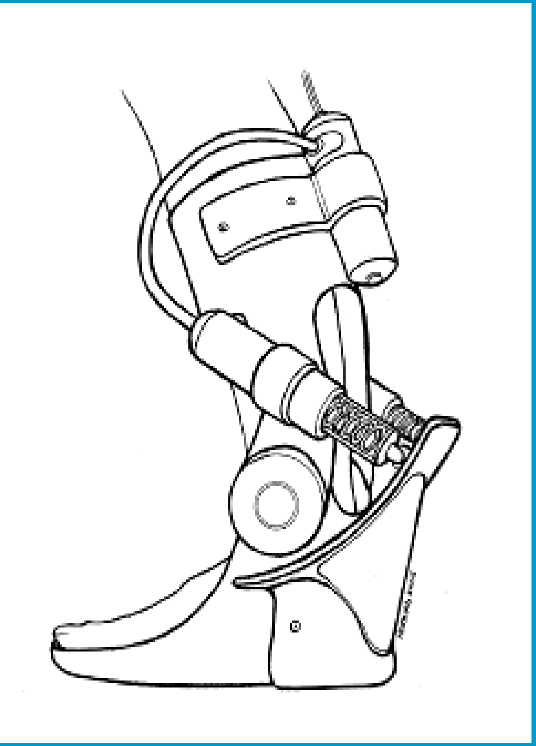
•New compliant actuator concept, utilizing ‘*structure controlled*’ tuning of stiffness.

•Power *input* is 1/3 of required power *output*.

•Motor size is reduced by a factor of 8.

•Actuator provides 100% of the *power* needed for ankle gait in a *0.84kg* package.

•Lightweight spring based actuator where the *spring* is the *gearbox*, *force sensor* and *compliant interface*.



Ankle Gait Robot Concept

Agrawal et al., Univ of Delaware

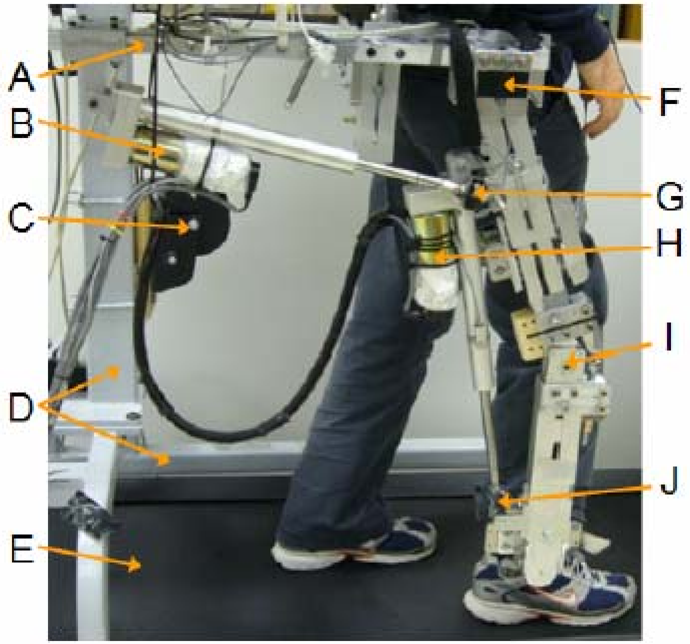


Fig. 1. Powered leg orthosis with a human subject. A: boom to support hip motor, B: hip linear actuator, C: spring-loaded winch to support device weight, D: walker to support the device, E: treadmill F: hip joint, G: load-cell on hip linear-actuator, H: knee linear actuator, I: knee joint J: load-cell on knee linear actuator.

Fig. 2. Gait training exoskeleton on the treadmill, a facility at University of Delaware. The subject walks on a treadmill and the active orthotic device is connected to the right leg. The computer display in front of the subject is for visual feedback of his gait trajectory during training.

LOPES, Univ Twente

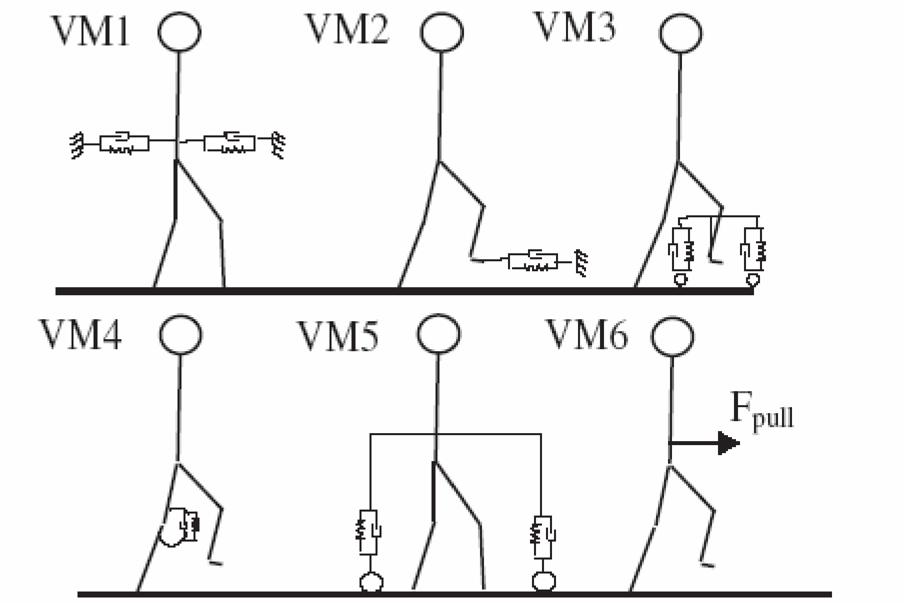
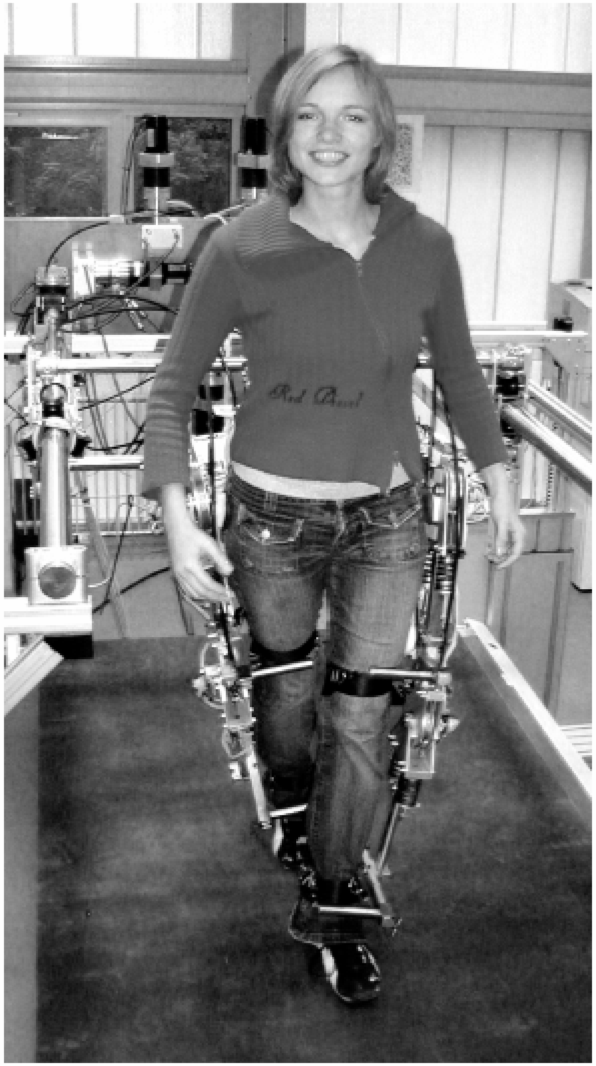


Fig. 2. Examples of Virtual Models(VM) to support gait. VM 1 supports the balance of the patient. VM2 assist the patient in the placement of the foot in the sagittal and frontal plane, which is important for dynamic balance and the speed of walking. VM3 enforces sufficient foot clearance using a virtual granny walker connected at the ankle. VM4 helps to stabilize the knee. VM5 is a virtual granny walker (partial) supporting the patient's weight. VM6 increases the patient's push off. (*is implemented)



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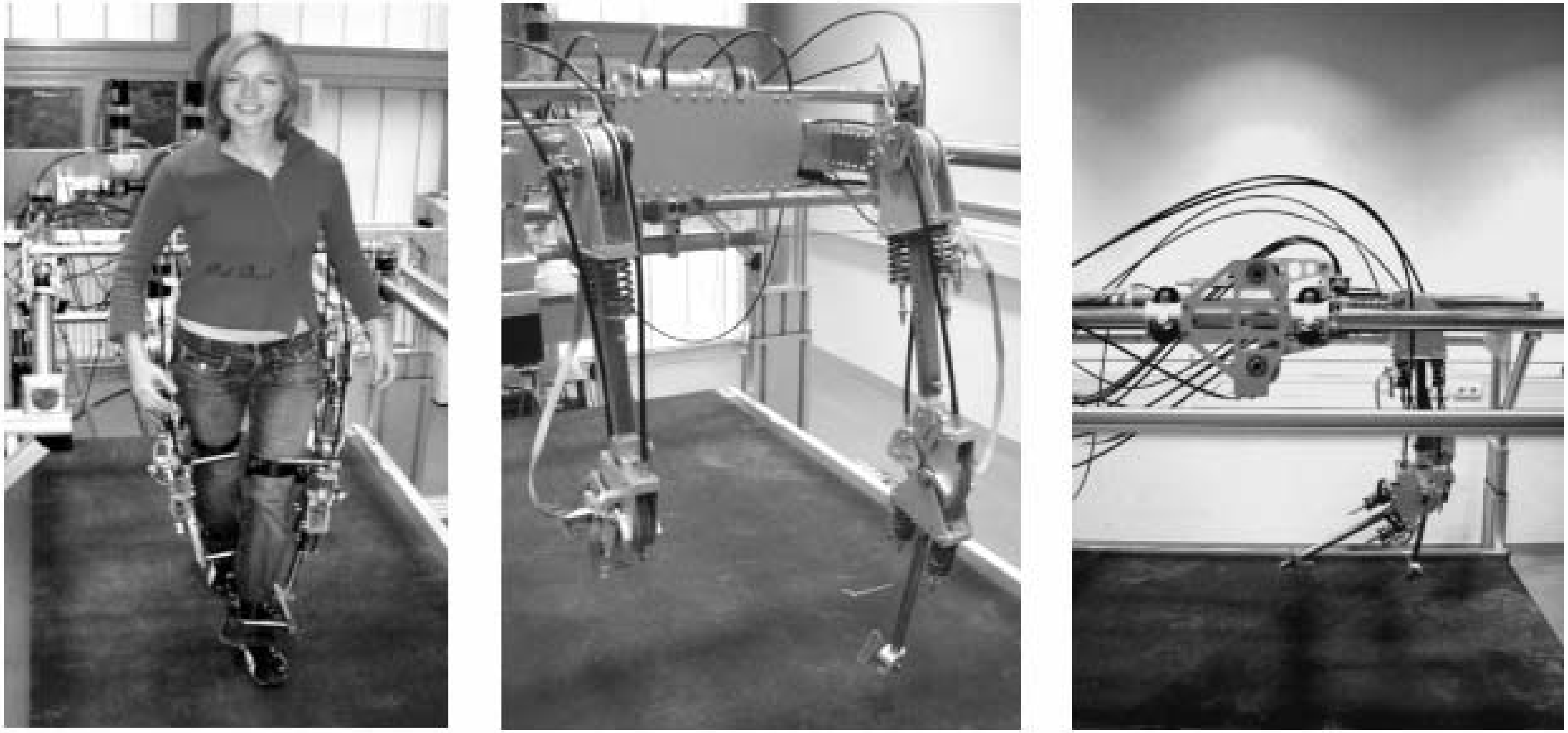
LOPES, Univ Twente



First prototype of LOPES with 8 actuated Degrees of Freedom by means of series elastic actuation. Knee flexion/extension, hip flexion/extension, hip ab/adduction of both legs are actuated as well as the horizontal movements of the pelvis.

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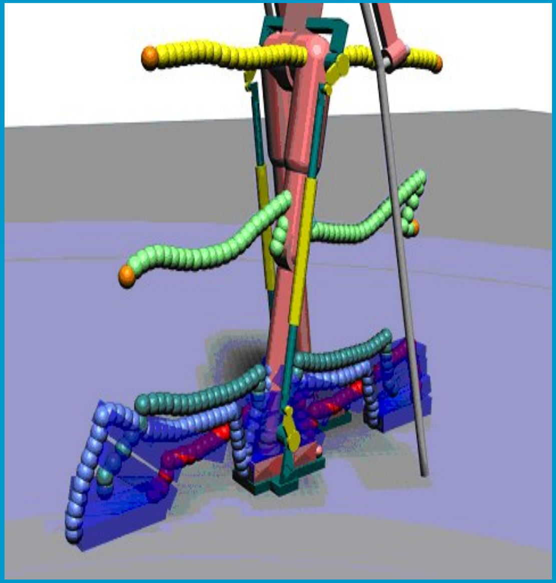
The Analysis, Design and Implementation of a Model of an Exoskeleton to Support Mobility

David Bradley, University of Abertay Dundee, UK
Camilo Acosta-Marquez, University of Abertay Dundee, UK

- The paper considers the design of a lightweight exoskeleton for mobility.
- Modelling links motion capture to the design.
- Evaluation with quarter-scale model.
- Use of crutches for static balance
- Operator control using controls embedded in crutches.



Motion tracks using Virtual Nastran model

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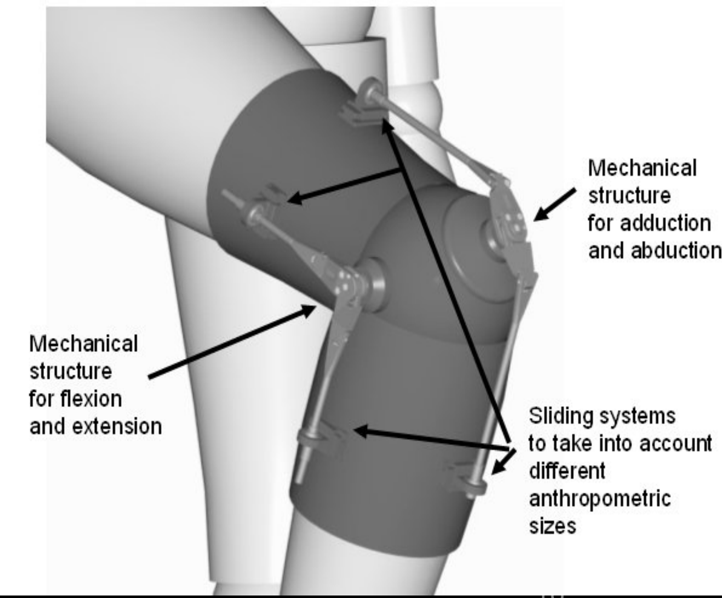
Analysis of age-related modifications of lower limb motor control strategies by using a wearable biomechatronic system

Silvestro Micera, ARTS Lab, Scuola Superiore Sant'Anna, Pisa (I)
G. Macrì, Scuola Superiore Sant'Anna, Pisa (I); A. Vaccaro, Scuola Superiore Sant'Anna, Pisa (I); J. Carpaneto, Scuola Superiore Sant'Anna, Pisa (I); M.C. Carrozza, Scuola Superiore Sant'Anna, Pisa (I); P. Dario, Scuola Superiore Sant'Anna, Pisa (I);

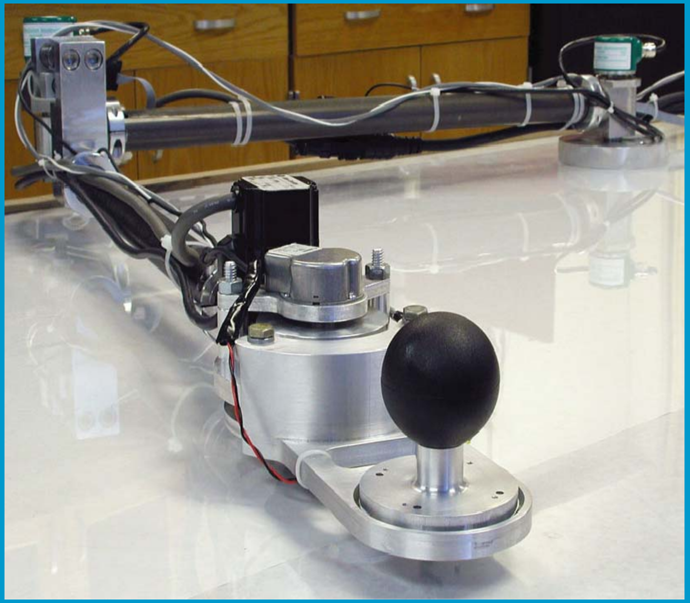
- A wearable biomechatronic system has been used to analyze lower limb motor control strategies in elderly people
- A "dual-task" approach has been used to investigate the effects of different cognitive efforts
- This method can provide measurements useful to investigate age-related deficits



Human Interaction with Passive Assistive Robots

Peng Pan, Kevin M. Lynch, Michael A. Peshkin and J. Edward Colgate
Laboratory for Intelligent Mechanical Systems
Mechanical Engineering Department
Northwestern University, Evanston, IL 60208

- Programmable constraint machines for rehabilitation and assistive devices
- The manipulandum implements smooth, hard, low friction constraint curves
- Subjects apply significant forces against the constraint in reaching tasks
- Including passive forces due to human arm dynamics and forces actively generation by muscles
- Some motor adaptation is also evident

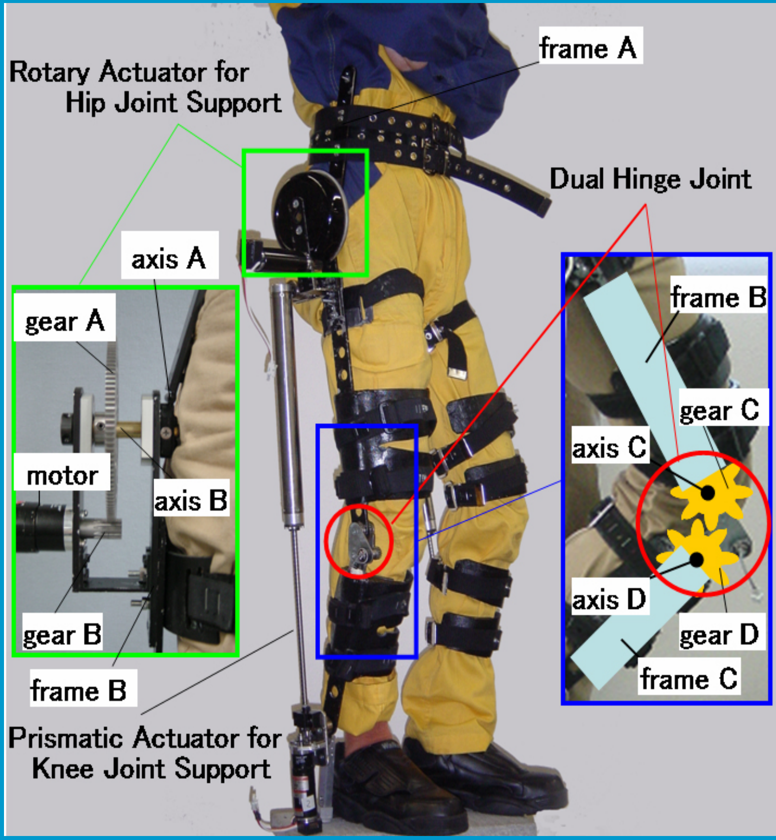


Two-joint cobot

Realizing a Posture-based Wearable Antigravity Muscles Support System for Lower Extremities

Takahiko Nakamura, Kazunari Saito, ZhiDong Wang and Kazuhiro Kosuge
Dept. of Bioengineering and Robotics, Tohoku University, JAPAN

- To support activities of physically weak persons, a wearable antigravity muscles support system is proposed
- In this system, Posture-based control algorithm is implemented to a wearable antigravity muscles support device
- In this algorithm, joint support moments are calculated based on user’s posture without biological signals
- Wearable Walking Helper-KH is developed as a wearable support device
- Experimental results show the effectiveness of the proposed system



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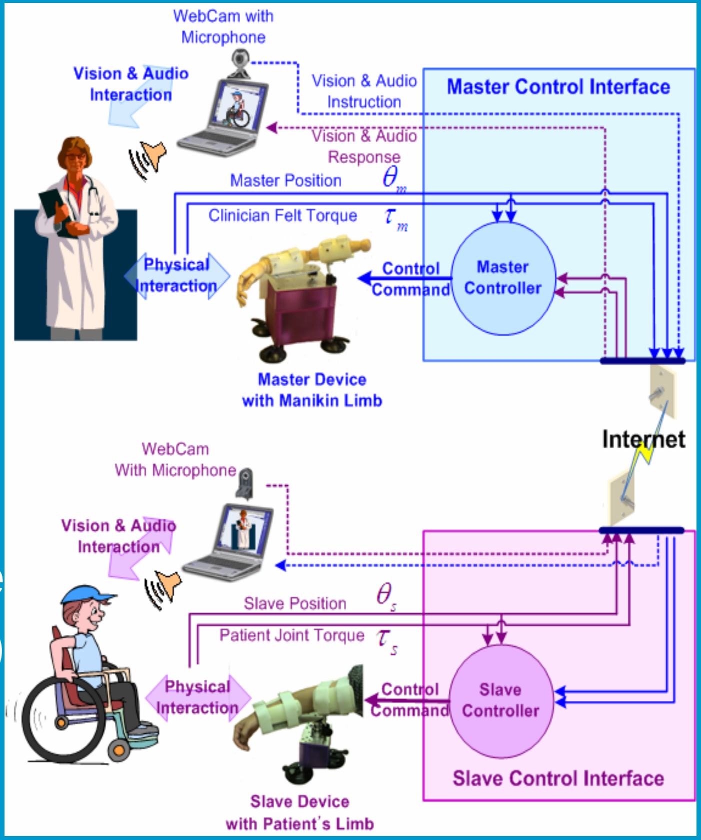
Causality-Based Portable Control System Design for Tele-Assessment of Elbow Joint Spasticity

Hyung-Soon Park, Rehabilitation Institute of Chicago, Chicago, IL, USA
Qiyu Peng, Rehabilitation Institute of Chicago, Chicago, IL, USA
Li-Qun Zhang, RIC & Northwestern University, Chicago, IL, USA

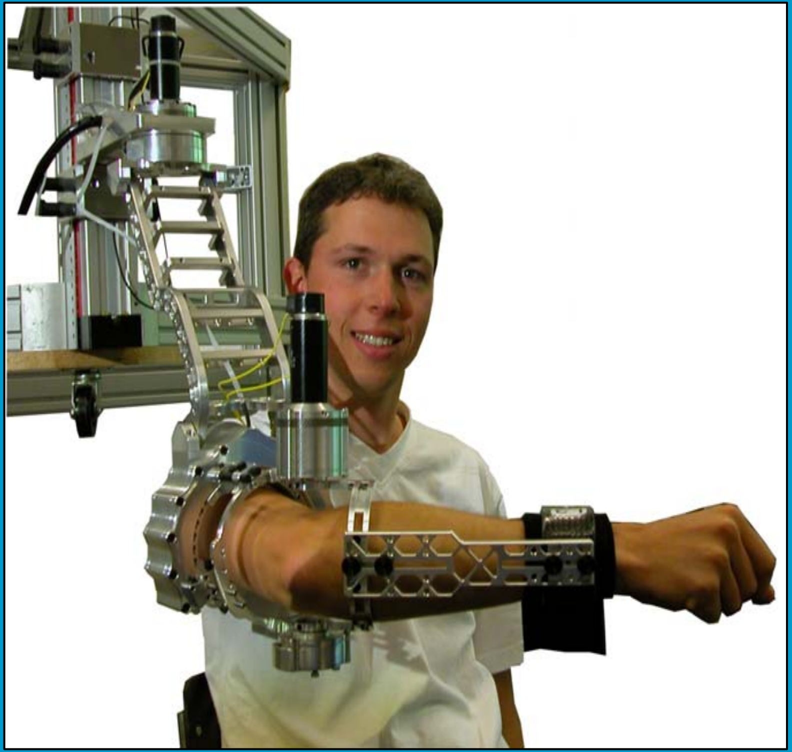
- Low-cost & portable tele-assessment system
    - Master: Haptic device with manikin arm mounted
    - Slave: Portable patient's limb stretching device
    - Audio-visual devices for video conferencing
    - PC /Laptop-based control with internet connection
- Causality-based control architectures
    - Two types task causality of tele-assessment tasks
        - Position Commanded Tasks (Clinician is active)
        - Force Commanded Tasks (Clinician is passive)
    - Causality-based control architectures for stability and transparency



Schematic diagram of the tele-assessment system

Robert Riener, ETH Zurich & University Hospital Balgrist
Martin Frey, Michael Bernhardt, Tobias Nef, ETH Zurich
Gery Colombo, Hocoma AG & University Hospital Balgrist

- "Patient-cooperative" strategies can take into account the patient's intention and efforts rather than imposing any predefined movement
- Three cooperative closed-loop controllers have been developed and tested
- Clinical evaluation will demonstrate if the therapeutic outcome will be improved by patient-cooperative rehabilitation robots

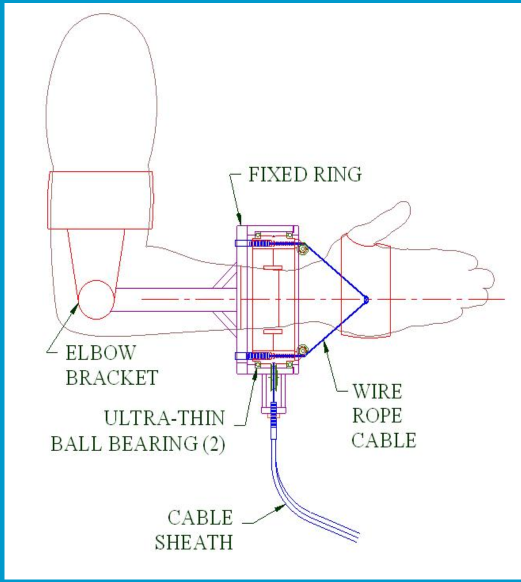


Armrobot ARMin used for patient-cooperative therapy

Exoskeleton with EMG Based Active Assistance for Rehabilitation

Dinal Andreasen, Georgia Tech, Atlanta Ga
Sarah Allen, Georgia Tech, Atlanta GA; Debbie Backus, Shepherd Center, Atlanta GA

- Exoskeleton for pronation and supination of the forearm
- Programmable mechanical impedance
- EMG based active assistance
- Cable driven orthosis



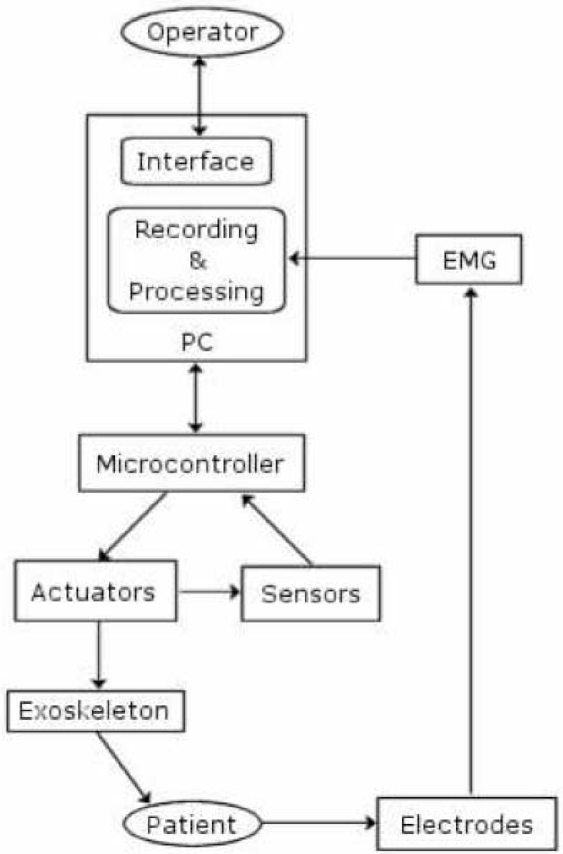


Fig. 1. Diagram of the hand rehabilitation system.

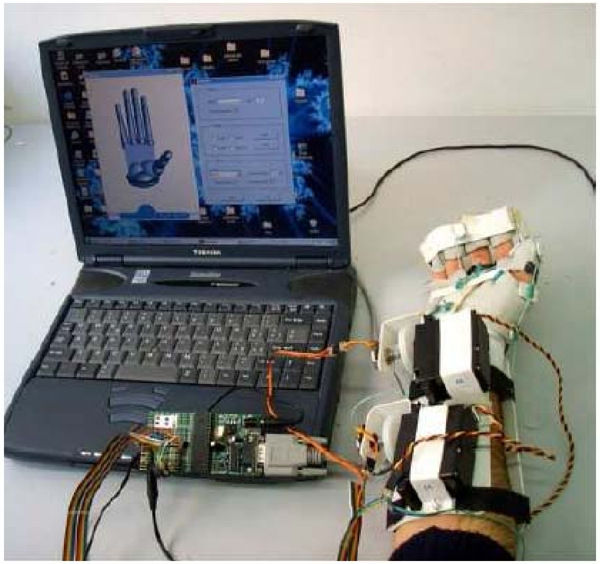
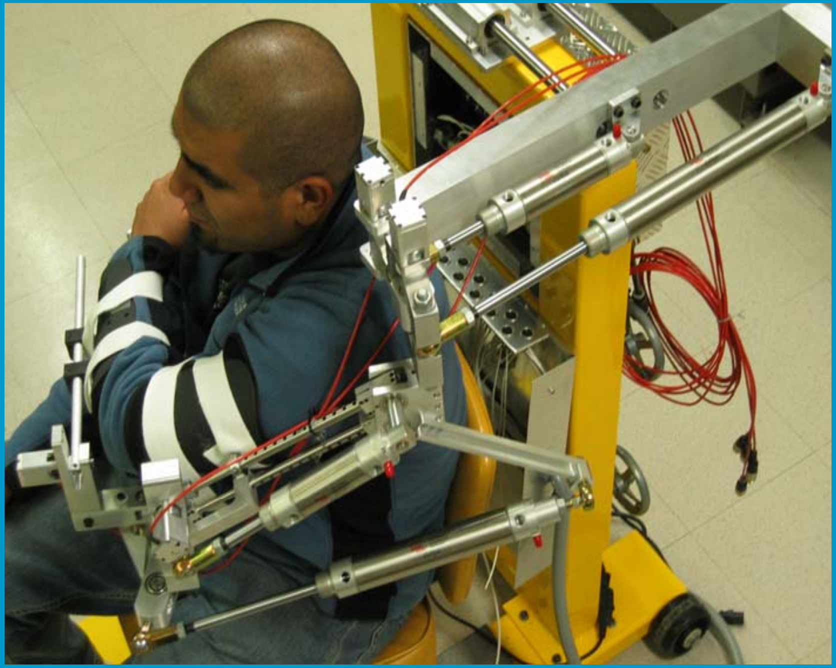


Fig. 2. Overview of the complete rehabilitation system.

A Pneumatic Robot for Re-Training Arm Movement after Stroke: Rationale and Mechanical Design

R. J. Sanchez[1], Jr., E. Wolbrecht[1], R. Smith[1], J. Liu, S. Rao[1], S. Cramer, T. Rahman[2], J. E. Bobrow[1], D. J. Reinkensmeyer[1]
1-University of California at Irvine, USA; 2-University of Delaware, USA

- This paper describes the development of a pneumatic robot for functional movement training of the arm and hand after stroke: Pneu-WREX.
- Pneu-WREX uses pneumatic actuators, non-linear force control, and passive counter-balancing to allow application of a wide range of forces during naturalistic upper extremity movements.
- Pneu-WREX allows individuals with severe motor impairment to practice functional movements (reaching, eating, and washing) in a simple virtual reality environment called Java Therapy 2.0.



Pneumatic-Wilmington Robotic Exoskeleton.

Rehabilitation Robot FRIEND II-
The General Concept and Current Implementation

Ivan Volosyak***, Institute of Automation, University of Bremen, Germany**
Oleg Ivlev**, Institute of Automation, University of Bremen, Germany**
Axel Gräser**, Institute of Automation, University of Bremen , Germany**

- ‘intelligent’ wheelchair mounted manipulator
- robot arm with 7-joint kinematics
- redundancy
    - sensors
    - actuators
    - processing methods
- smart devices, ambient intelligence
- intelligent home

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Casus: Neuromuscular diseases

600 variants identified

- Muscular Dystrophies (Duchenne DMD)
- Motor Neuron Diseases (Spinal Muscular Atrophy SMA)
- Inflammatory Myopathies
- Neuromuscular Junction Diseases
- Endocrine Abnormalities
- Peripheral Nerve Diseases
- Metabolic Diseases of Muscle

Over 1 mln. people affected in USA

- SMA alone 12 .. 40 per mln of the adult population
- Neonatal from 40 per mln (USA) to 200 per mln (SA)

Spinal Muscular Atrophy (SMA)

Inherited

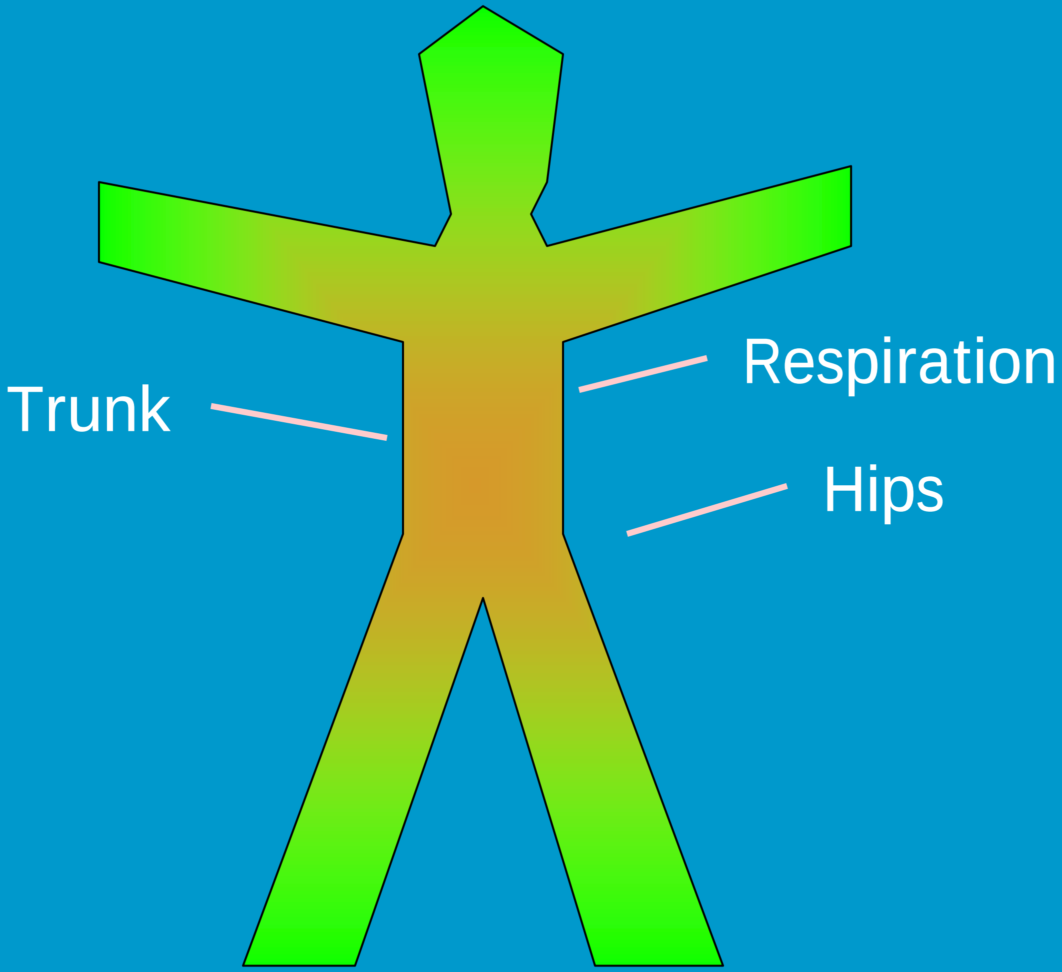
Affects motor neurons voluntary muscles

Senses not affected, normal or above-average intellect

Incurable

Progressive

Spinal Muscular Atrophy (SMA)



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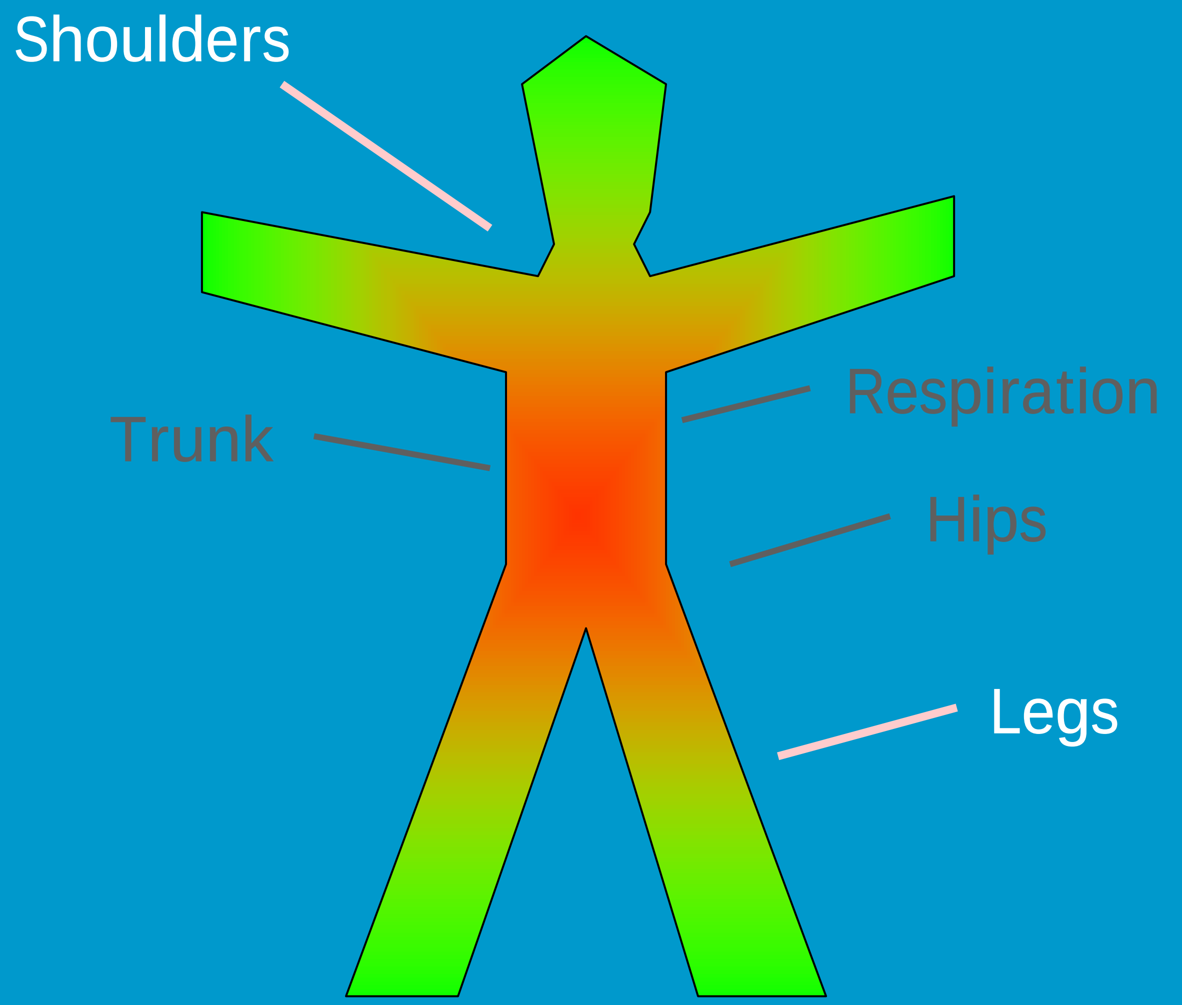
Spinal Muscular Atrophy (SMA)



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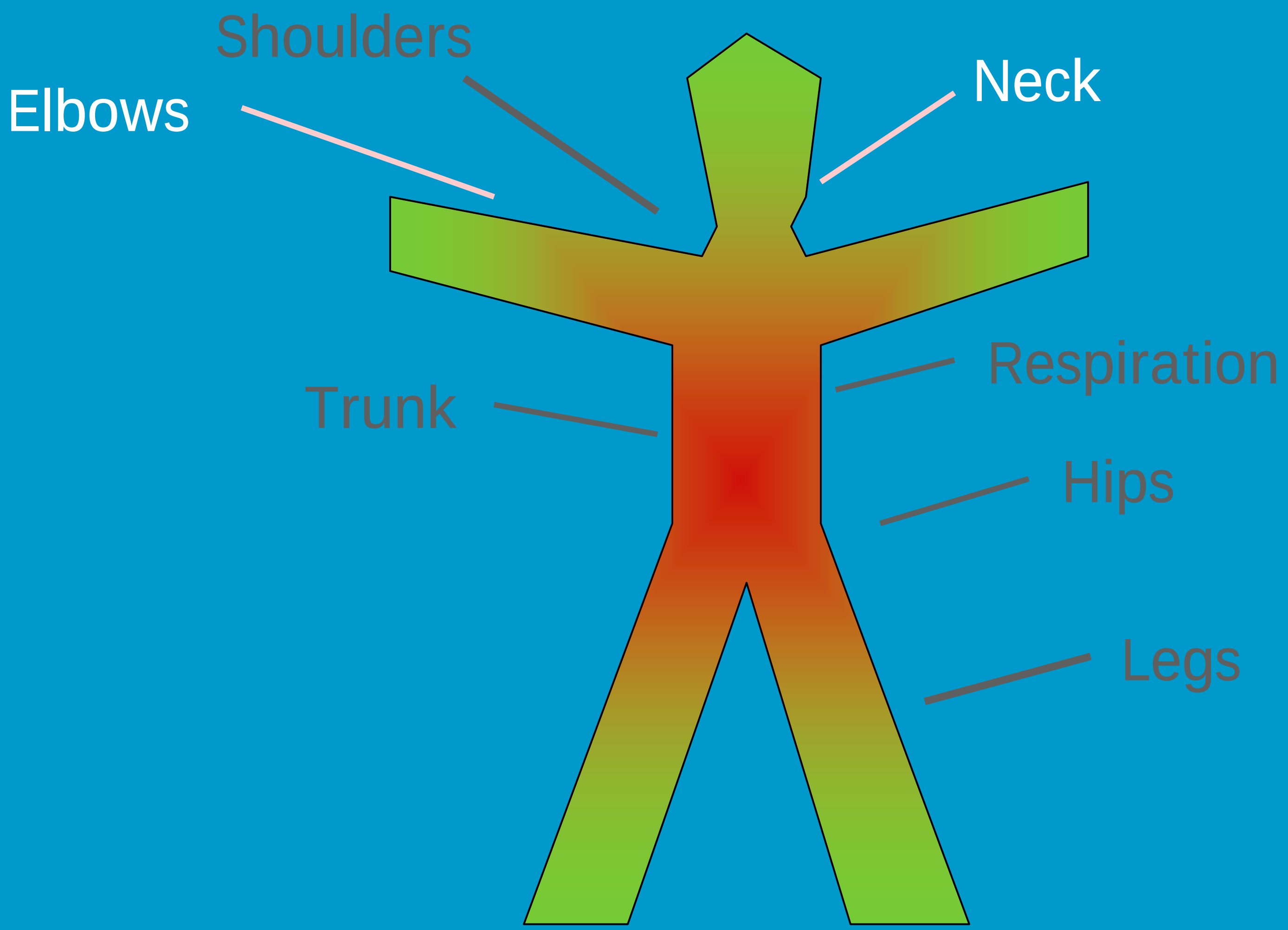
Spinal Muscular Atrophy (SMA)



Two of our volunteers!

A

Academic degree

Head support

Scoliosis, A had surgery, B not

Wheelchair bound

Arm on armrest

Good sense of touch

Slight deformations in hands

B

Available assistive devices

1. Rehabilitation robotic manipulators

No use of hand function
Control by joystick

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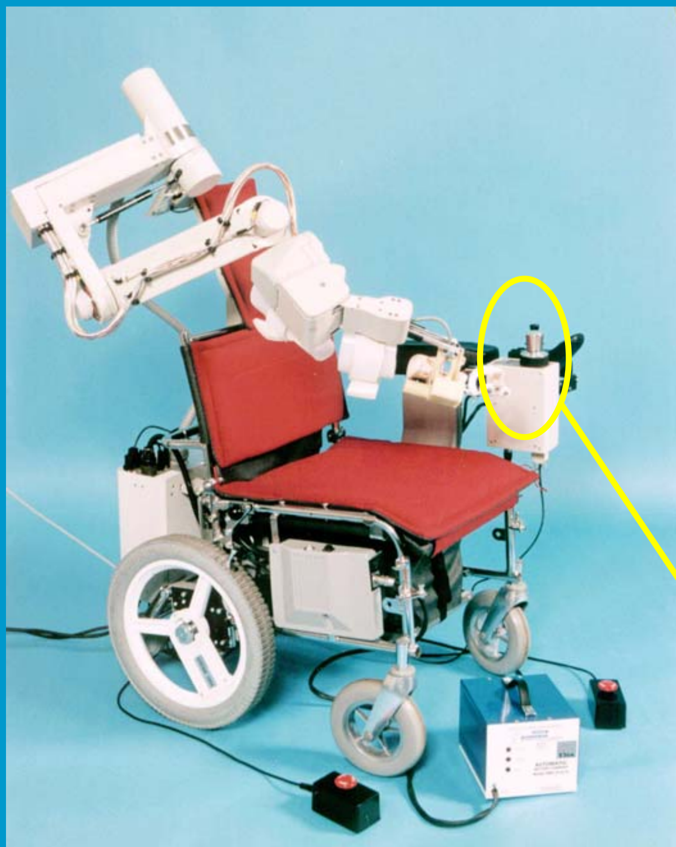
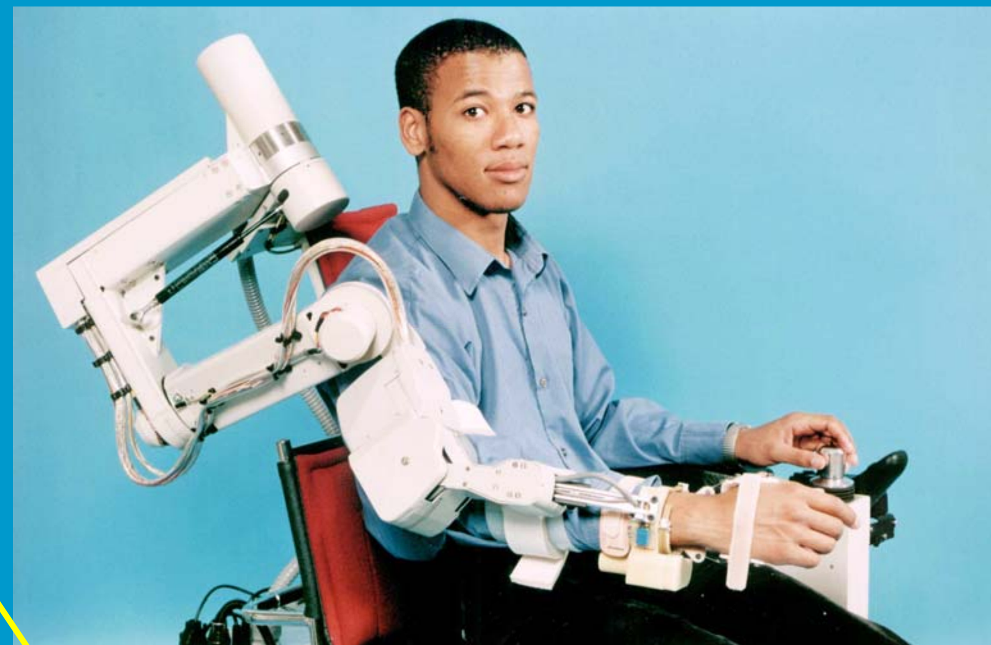
Available assistive devices

2. Powered orthotic devices





Use of hand function
Control by joystick

Available assistive devices

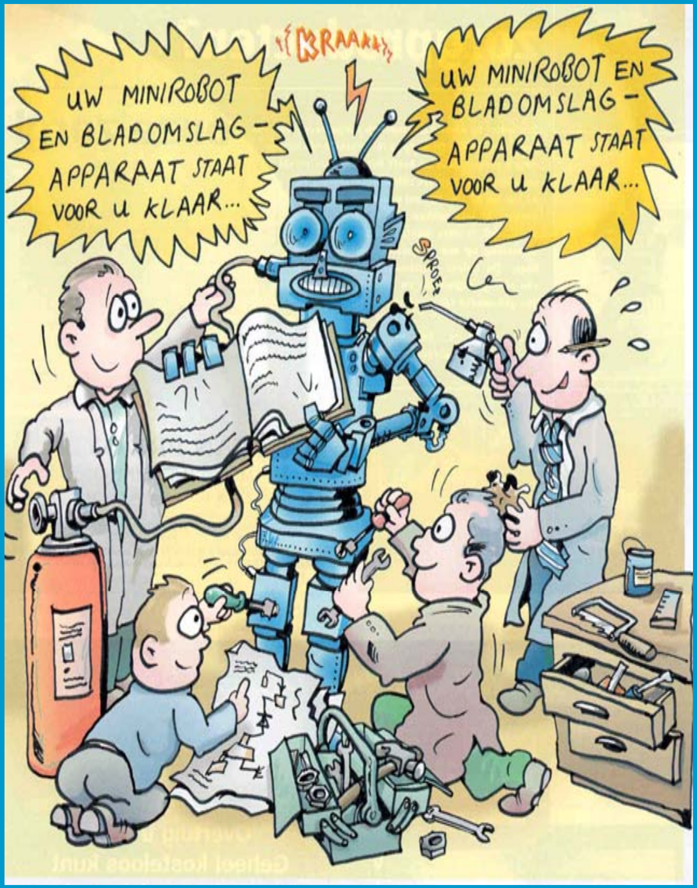
3. Passive orthotic devices: *static balance*

Universal Healthcare Systems

Use of hand function
No separate control

Clinically driven approach
Home visits

- Independence
  - Personal Hygiene
  - Cooking, eating
  - Computer work
- Social activities
  - Have dinner
  - Shake hands
- Trunk balance
  - Arm rest essential
- Inconspicuous!

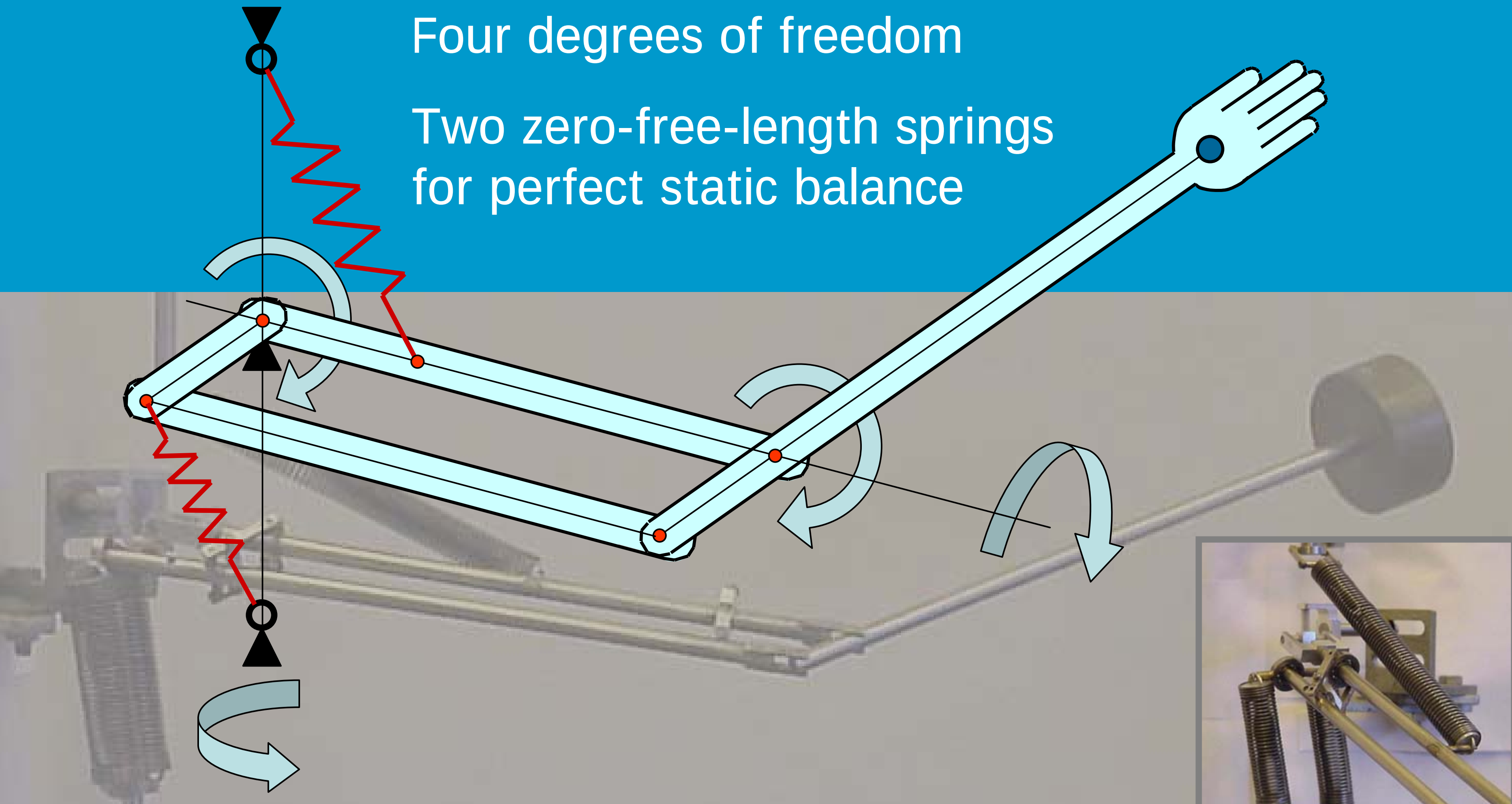


"Your page turner is ready..."

Anthropomobile balanced arm

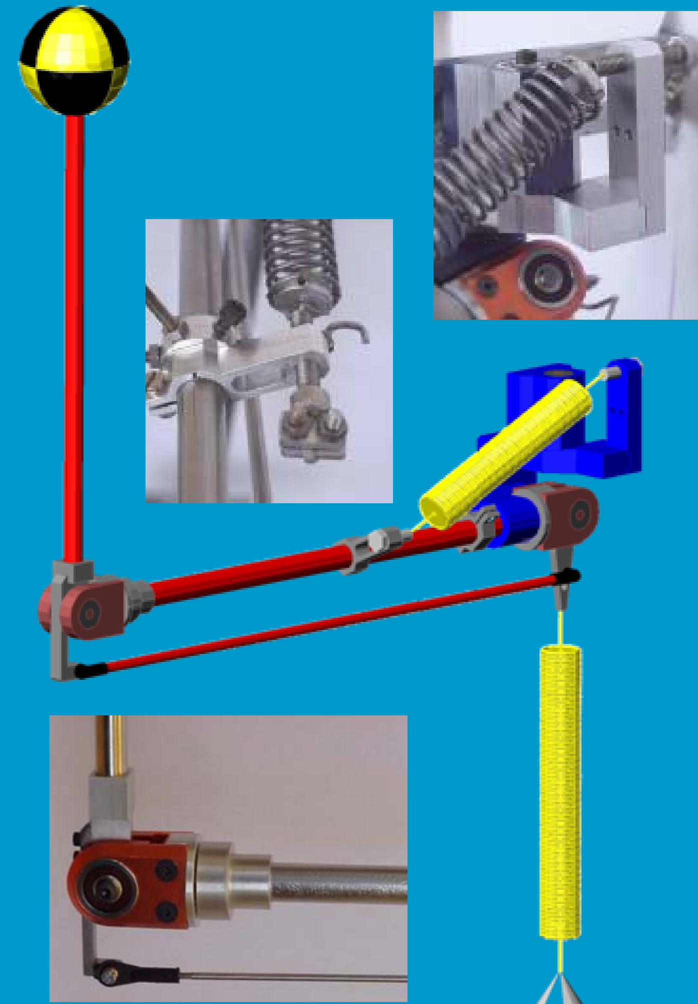
Four degrees of freedom

Two zero-free-length springs for perfect static balance



Herder and Tuijthof (1998)

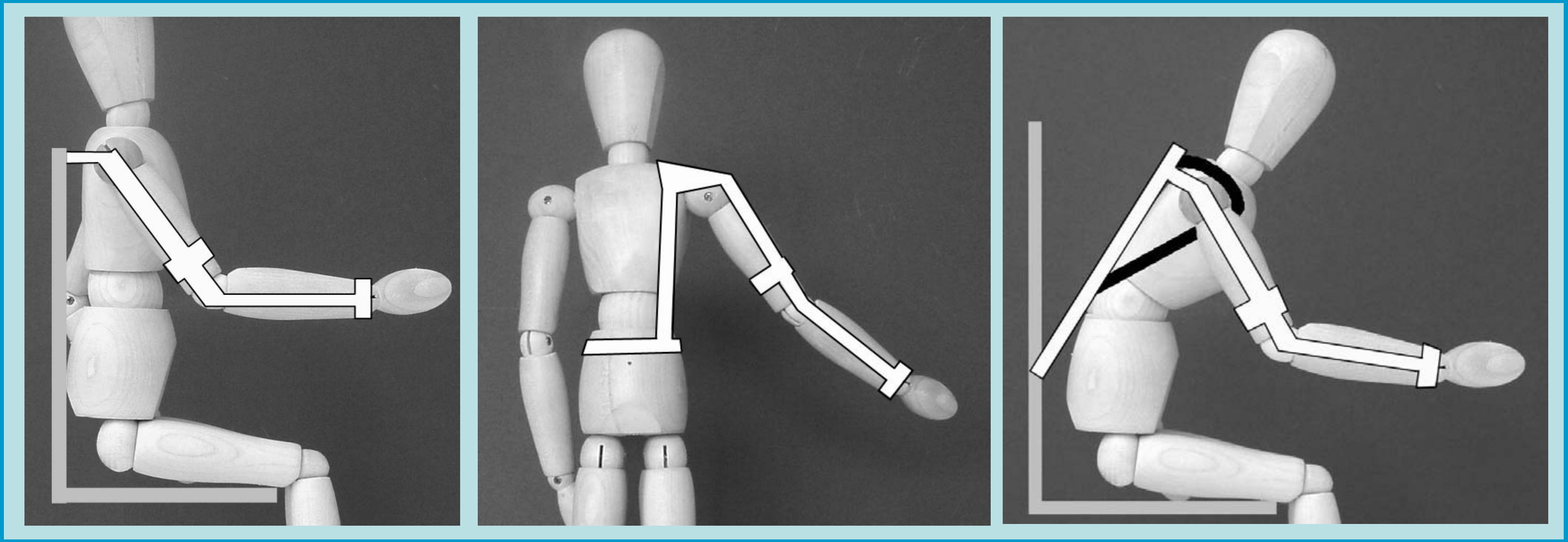
Anthropomobile balanced arm



- Variable stiffness control
- McKibben actuators
- Statically balanced
- Inherently safe

Conceptual design

Mechanism alongside the user's arm



Attached to wheelchair	Attached to the user's trunk	Hybrid form with additional segment
Insufficient mobility	**Respitatory hamper**	**Excessive complexity**

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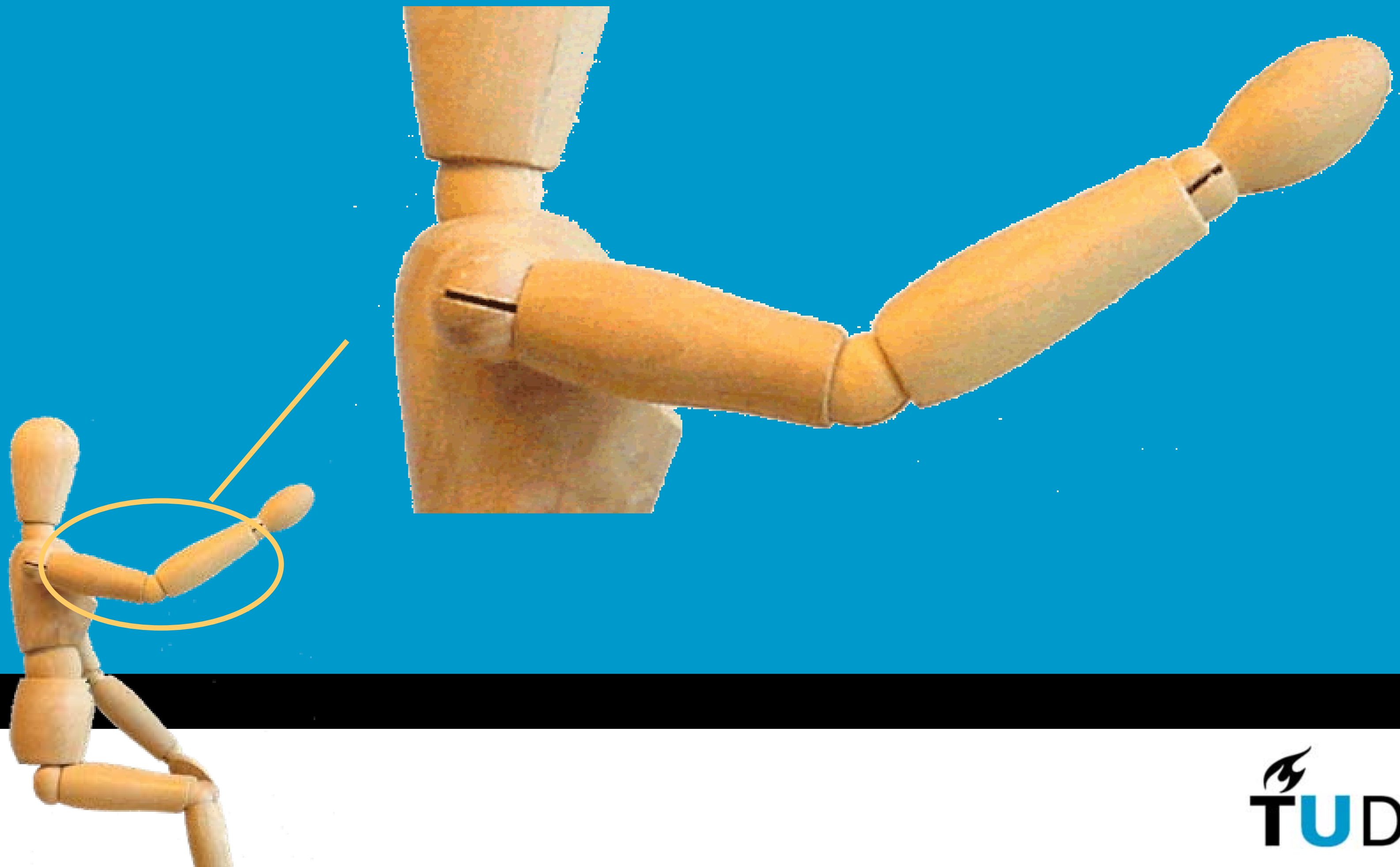
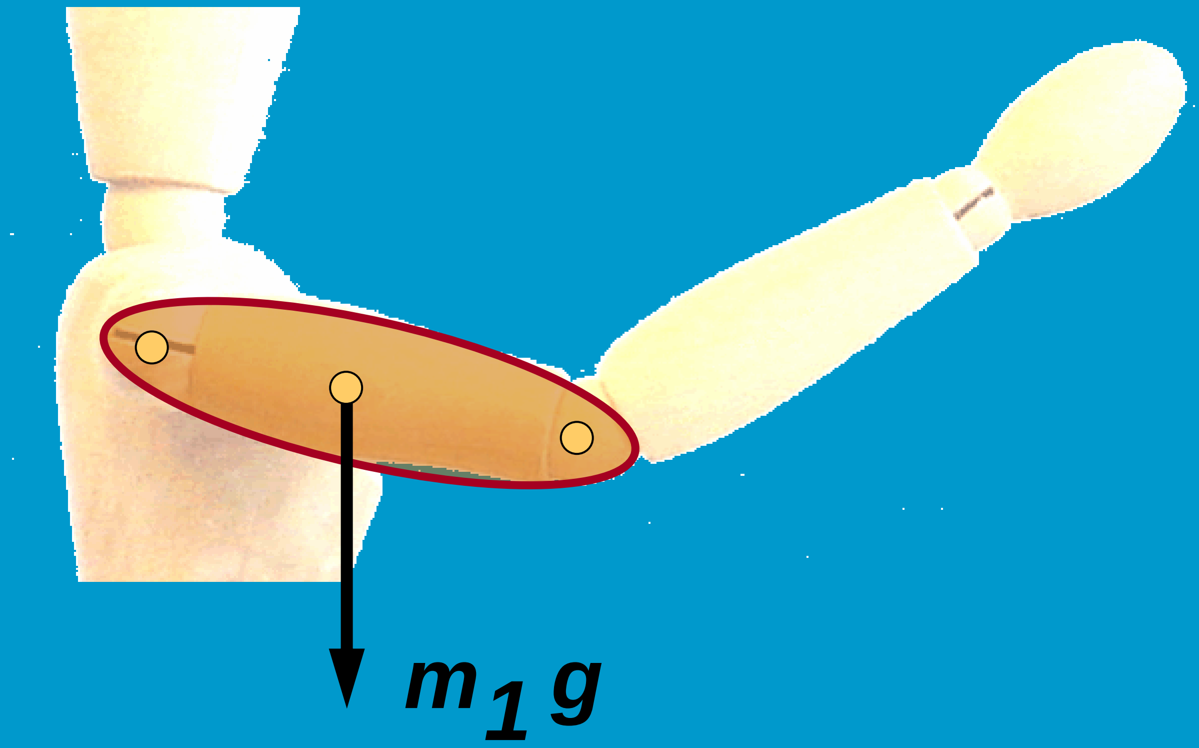
Conceptual design

Force analysis revisited



Conceptual design
Force analysis revisited



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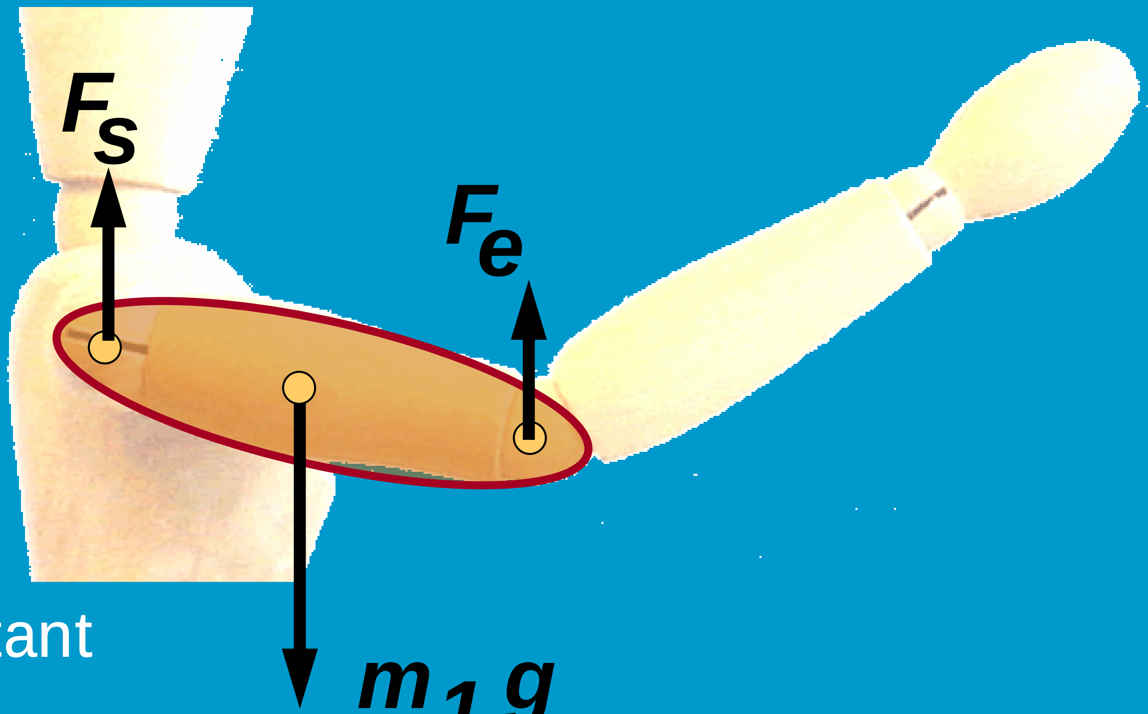
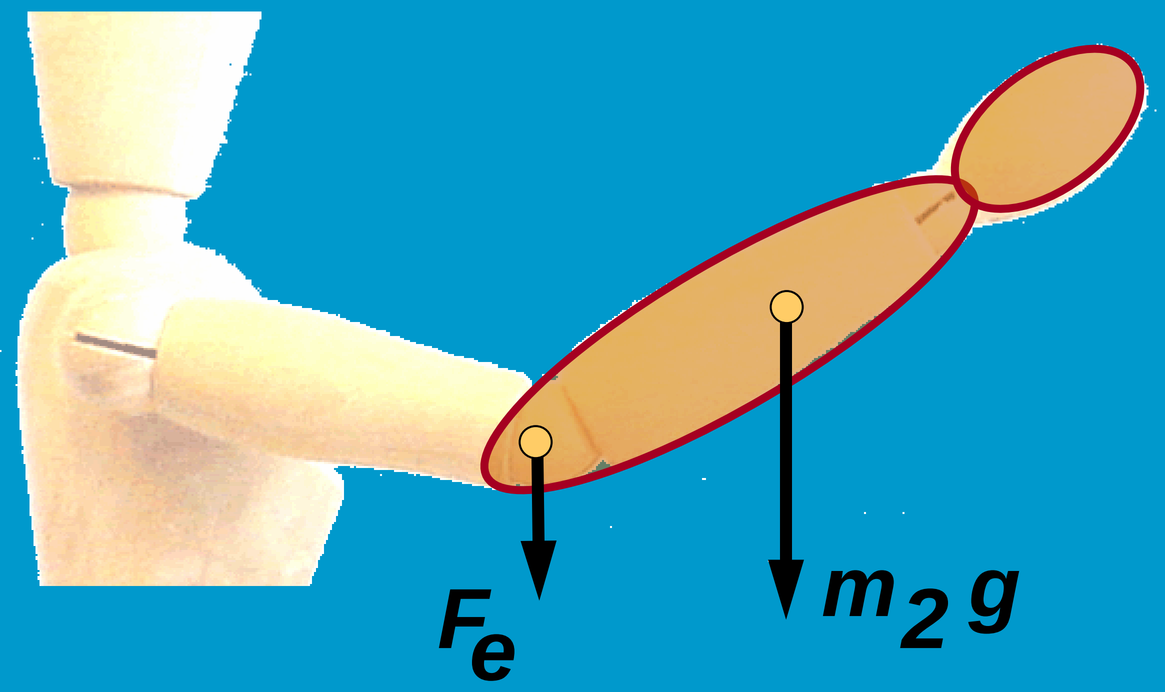
Conceptual design
Force analysis revisited



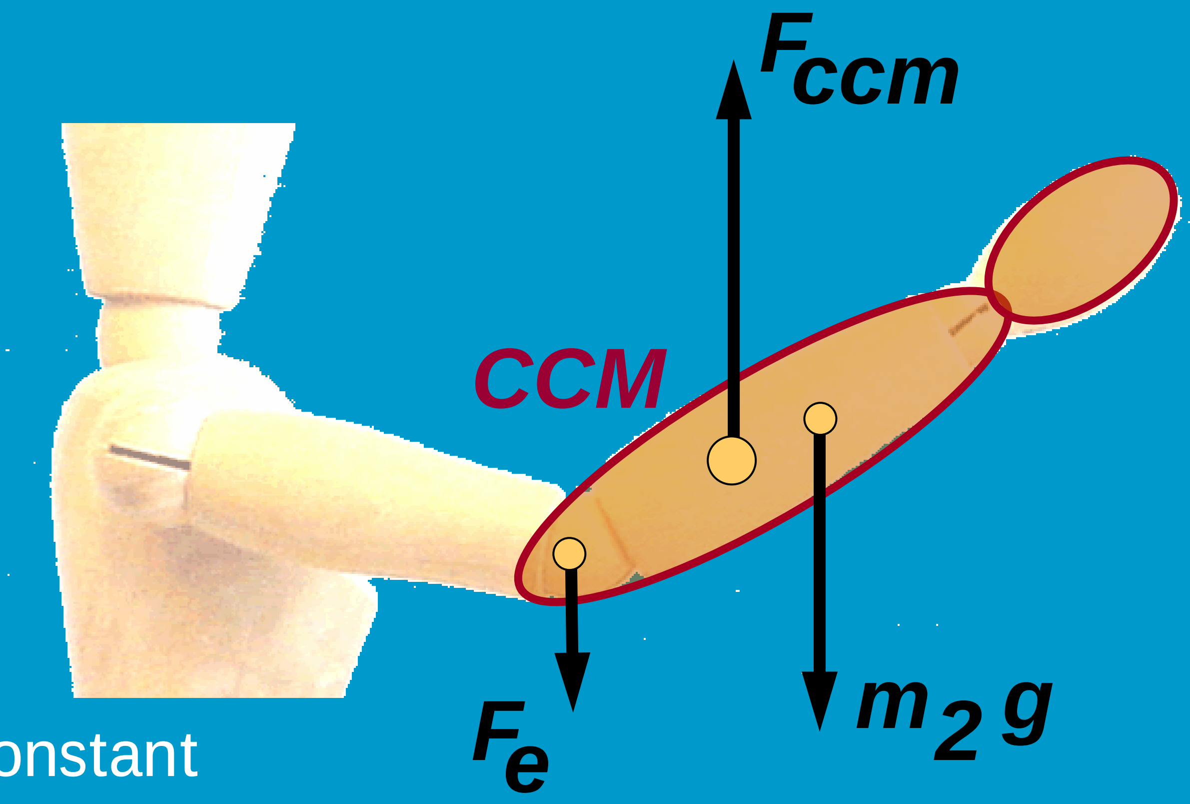
F_e and F_s constant
F_s by shoulder

Conceptual design
Force analysis revisited



Conceptual design

Force analysis revisited



F_e and m_2g constant

F_{ccm} for complete arm

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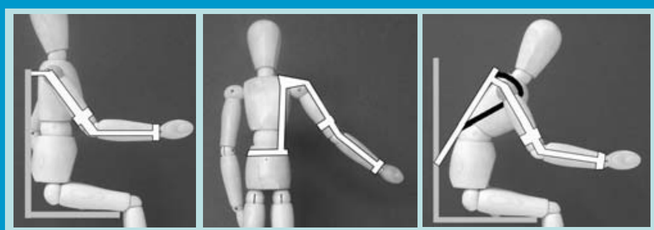
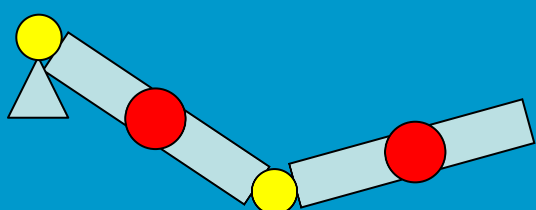
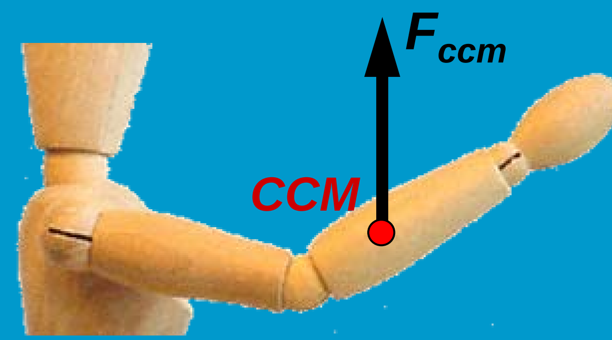
Biomechanics

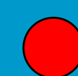
Change of Design Paradigm





Balancing 2-link 4DoF arm





Balancing a point mass!

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Conceptual design

- Problem of carrying a two-segmented 4dof arm reduced to carrying a point mass through space!
- Mechanism no longer alongside arm
- Only one attachment point for complete static balance

Anglepoise (Carwardine, 1934)

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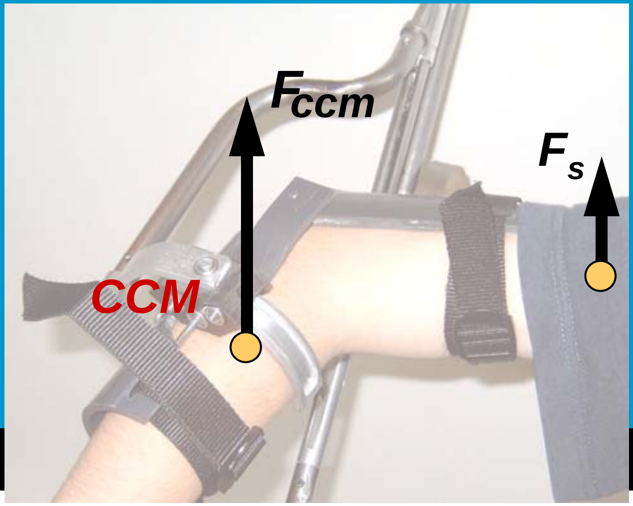
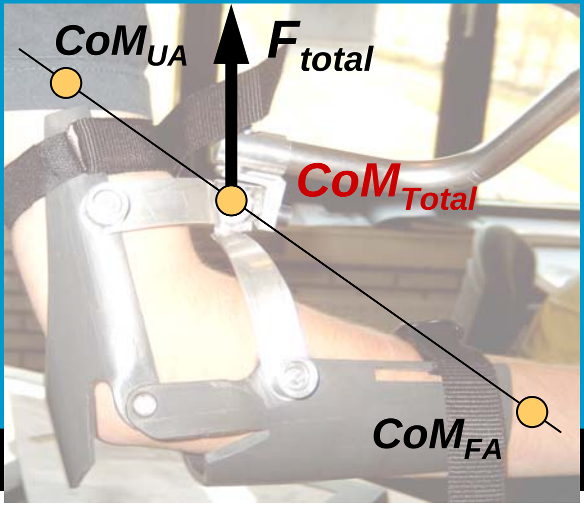
Biomechanics

Comparison of two support methods





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Biomechanics
Comparison of two support methods

Support mechanism attached at CCM:

Balances 100%

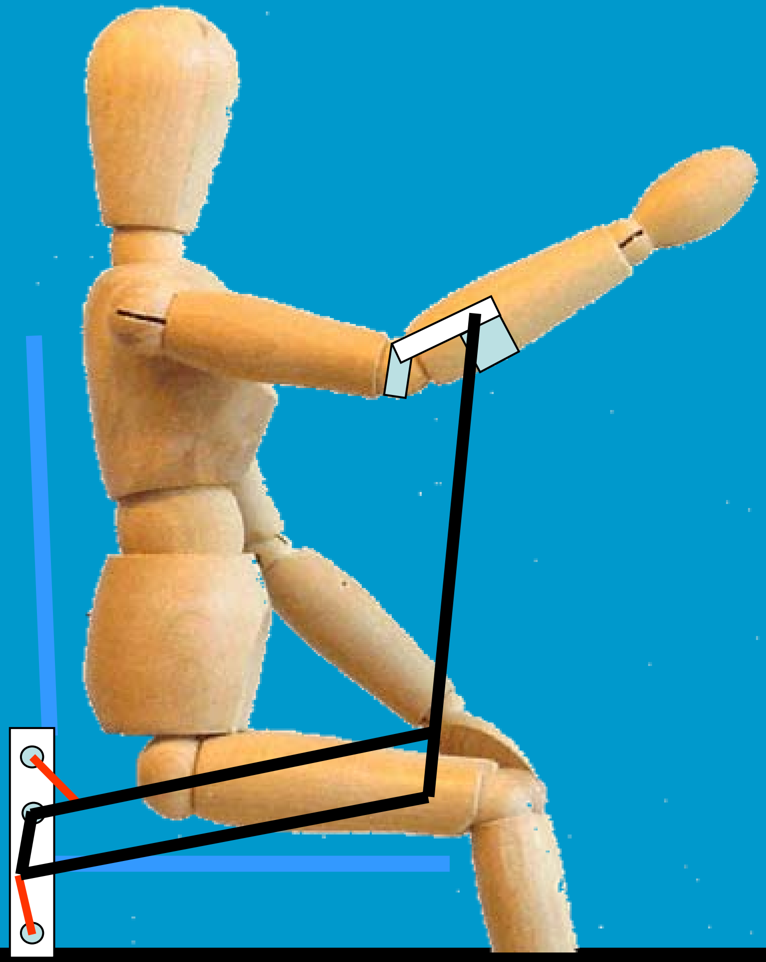
Carries ca. 75%

Support mechanism attached at CoM_{Total}:

Balances 100%

Carries 100%

Conceptual design
Working principle



No longer alongside arm
Arm rest maintained
Inconspicuous

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Preliminary clinical testing
Moving arm up

Herder, Tomazio, Cardoso, Gil and Koopman, 2002

Patent pending

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ARMON (Mark II)
Patients with the device

Patent pending

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ARMON (Mark III)

First commercial product

Patent pending

www.microgravityproducts.com

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Development of ARMON

- Mark I:
  - Proof of novel CCM balancing principle
  - Single fitting and aesthetics highly appreciated
- Mark II:
  - Improved range of motion, no interference
  - Actively adjustable gravity balancing
  - Improved appearance and fitting design
- Mark III:
  - Further improved balancing quality and reduced friction
  - Reduced box volume, general sophistication

Thank you for your attention

Eelke drinking a glass of water with ARMON Mark II

Acknowledgment

- MSc Students: Sergio Tomazio, Luis Cardoso, Jorine Koopman, Clara Gil Guerrero, Wendy van Stralen, Pieter Lucieer, Sabine Gal, Tonko Antonides
- Physician: Imelda de Groot MD
- Patients: In total over 12 patients tried the device
- Patient organization: Dutch Neuromuscular Disease Association (VSN)
- Company: Microgravity Products (MGP), Niels Vrijlandt, Tonko Antonides, Marijn Cloosterman, for manufacturing the prototypes and images.

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