Towards Lower Limbs Rehabilitation and Walk Assist devices

Dr M. Bouri

EPFL,
Laboratoire de Systèmes Robotiques
Institute of MicroTechnology

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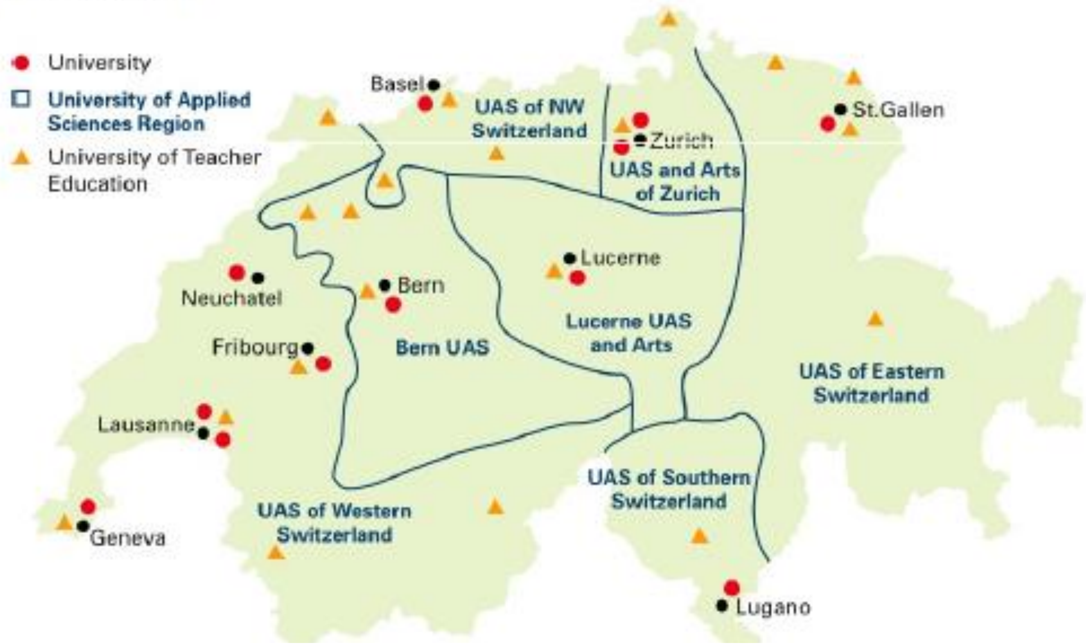
Dr M. Bouri

12 High schools and Universities
117,000 students (2007/08)

8 Universities of Applied Sciences
60,000 students (2007/08)



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Robotics for Medical Rehabilitation and Assistance:

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Institute of MicroTechnology

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The presentation

Why robotics is suitable for Rehabilitation ?

Sitting Position Rehabilitation Devices

Verticalized Rehabilitation Devices

Walk Assist Devices - Exoskeletons

Motor Rehabilitation: What is and Why?

Rehabilitate a limb is train it in order to recover the mobility

Rehabilitation as clinically practiced

Motor Rehabilitation: How?

- Mobilisation
- Evaluation
- Interaction

Robotics is a solution for rehabilitation because of the presence of elements related to actuation (through actuators) and instrumentation (through sensors)

Mobilisation

- **Structures** that allow the **transmission of efforts** from one point to another point.

- Actuators producing **mobilization** and providing effort feedback

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Evaluation

Thanks to instrumentation (**Sensors**).

- By closing the loop for the control purposes.
- To follow the progress during the rehabilitation phasis.
- For security

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Interaction

Strategies of rehabilitation

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Part1-

Sitting position devices

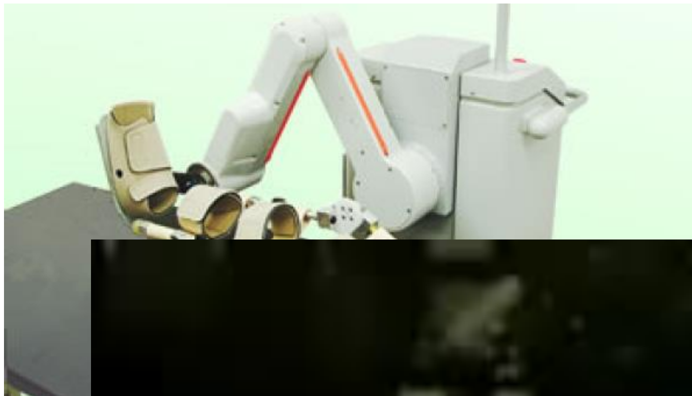
Control strategies – Basics

Mobilization, Impedance control,

Closed Loop Electrostimulation

Rehabilitation by a robot : Simple solutions- Passive mobilisation

ONLY Moving device TM2 from Yaskawa



Mobilize and Interact

The strategy :

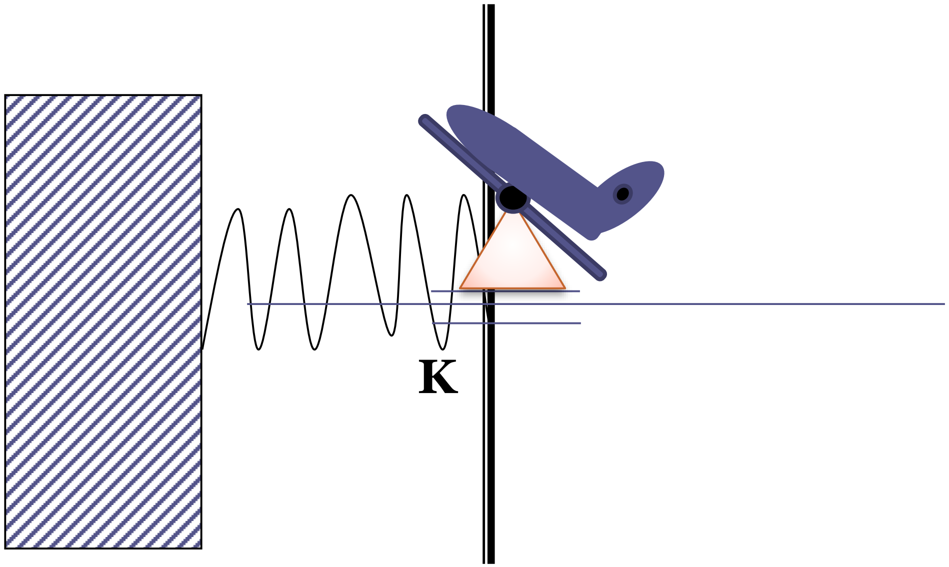
- Rehabilitation by learning.
- Learning by Errors

➡ Rehabilitation by Error

Robotic Rehabilitation

Example of "Mobilize and Interact"

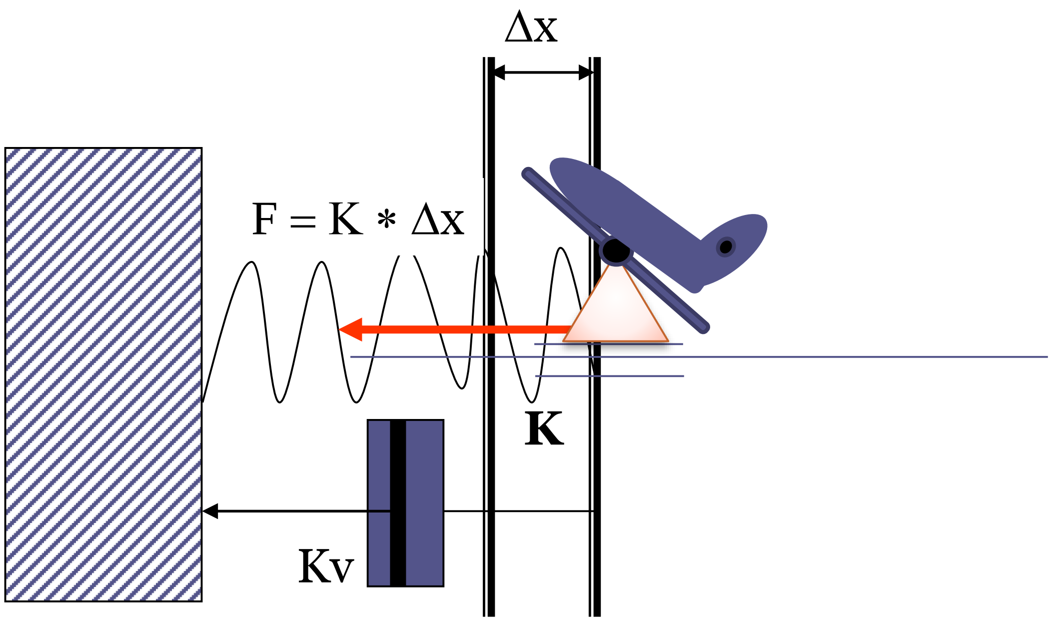
Impedance control



Robotic Rehabilitation

Example of "Mobilize and Interact"

Impedance control

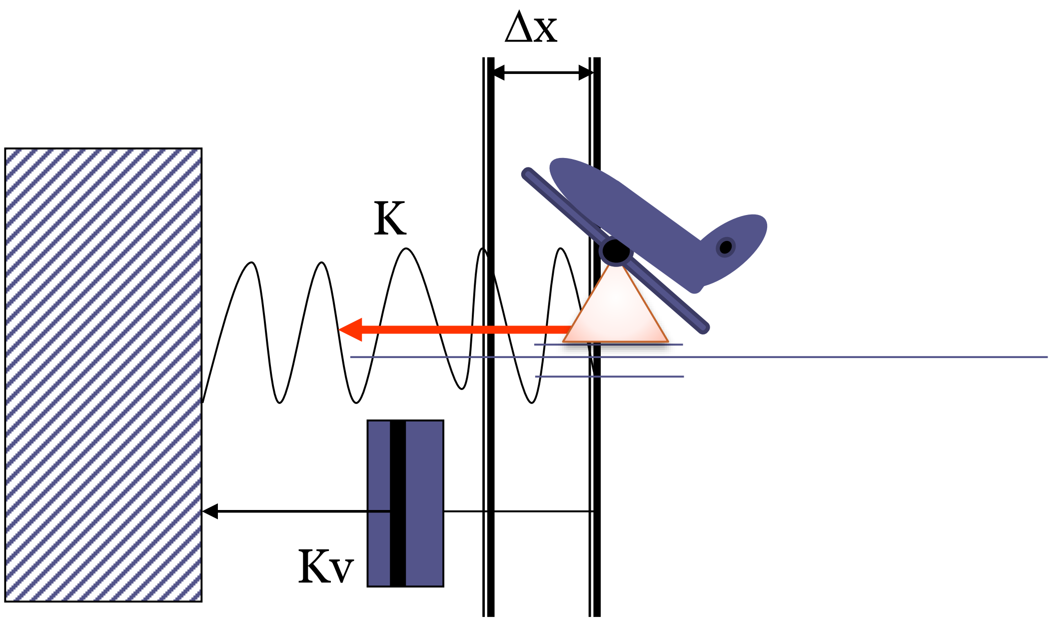


F = K * Δx + Kv * d(Dx)/dt

Robotic Rehabilitation

Example of "Mobilize and Interact"

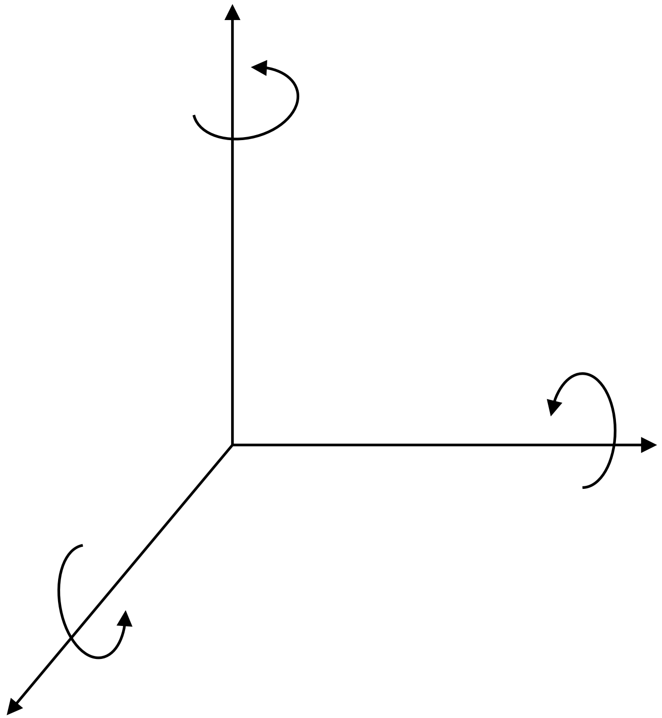
Impedance control

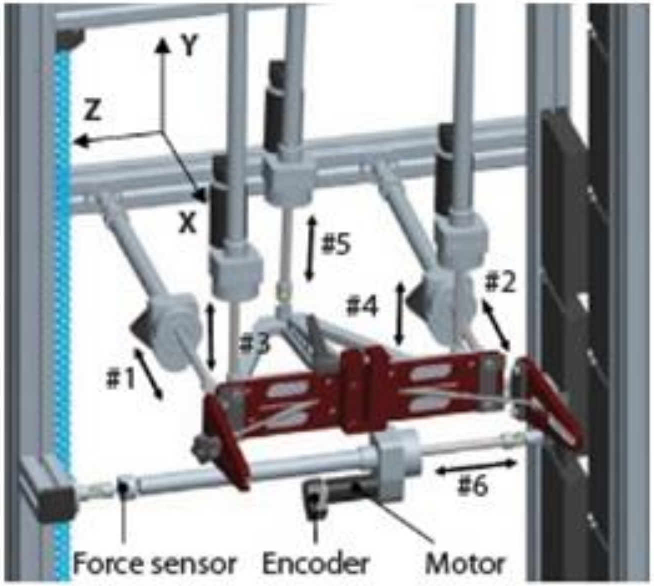


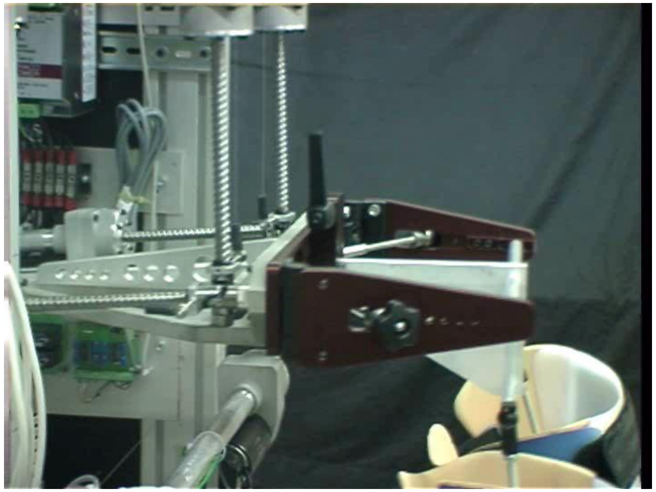
$$Fmot = Kp * \Delta x + Kd * d(\Delta x)/dt$$

Robotic Rehabilitation Mobilize and Interact

multi freedom case :
Pelvic Orthosis and selective impedance control

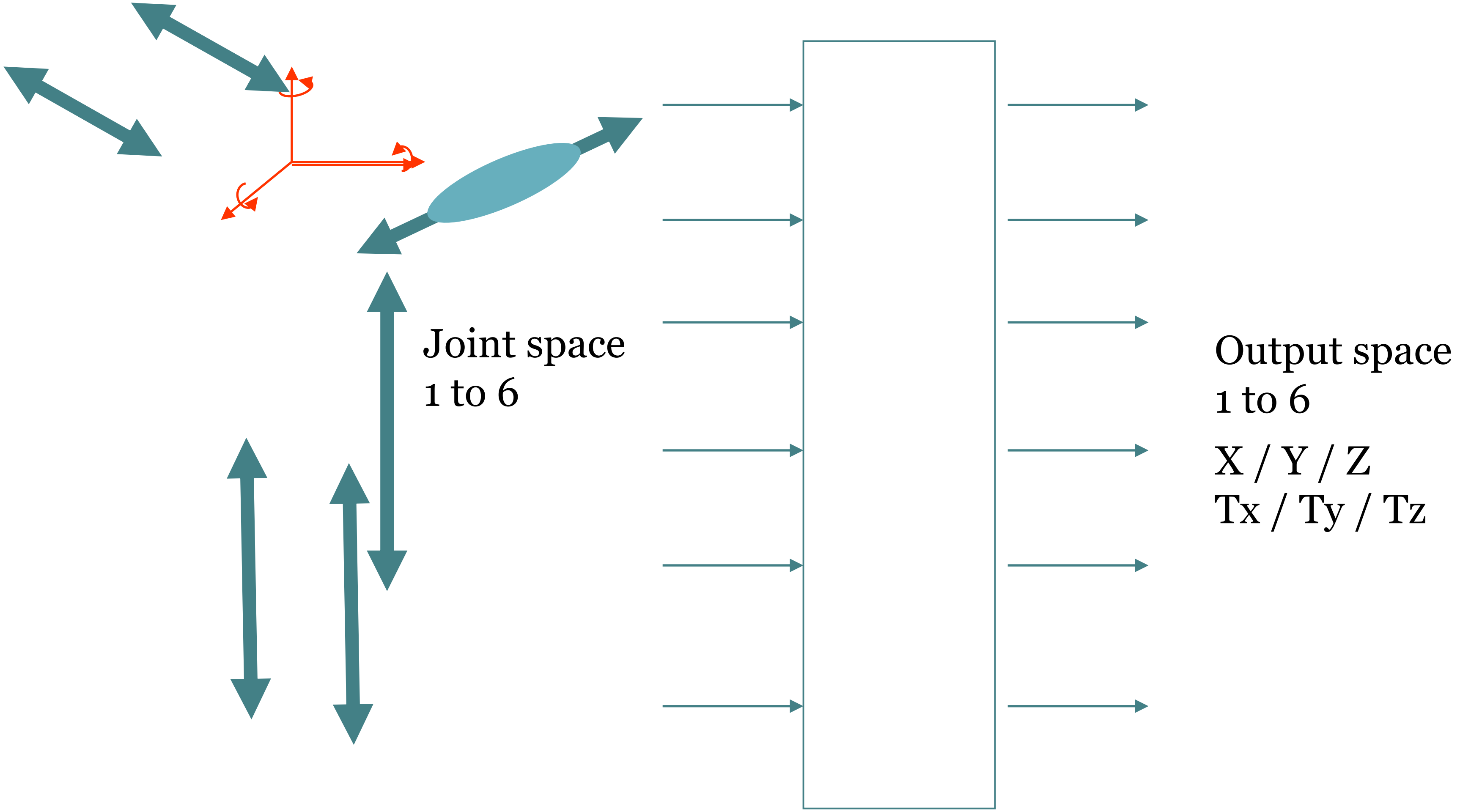






Robotic Rehabilitation Mobilize and Interact

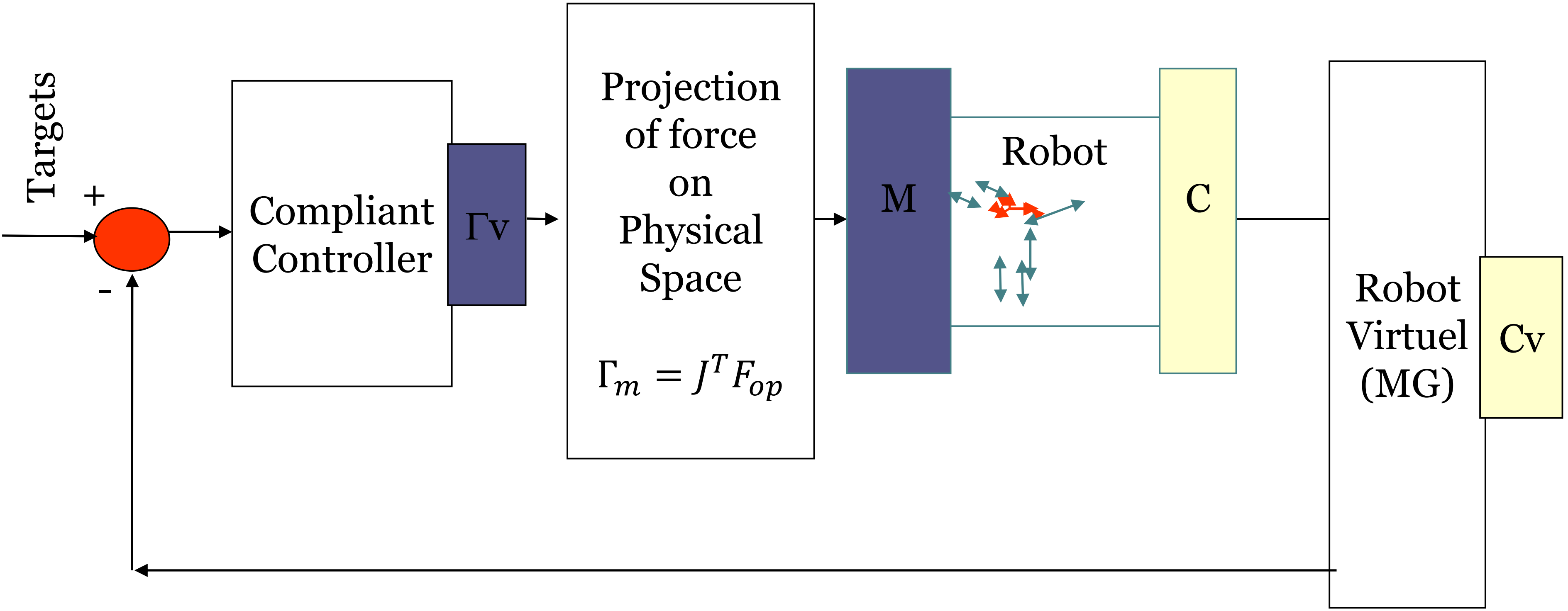
Multi freedom case, What needs to be done:



Compliance in joint space implies a coupled compliance in the output spece (X Y Z Tx Ty Tz)

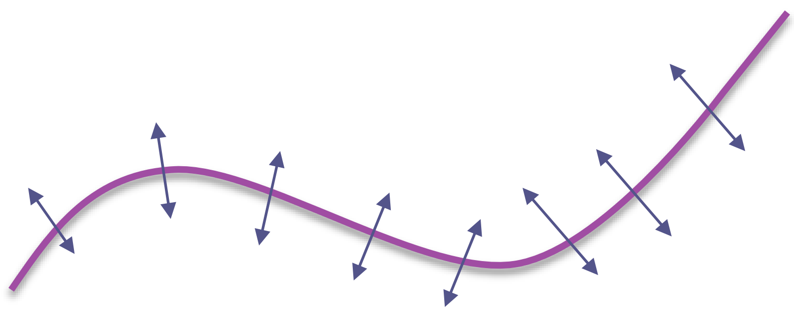
Robotic Rehabilitation Mobilize and Interact

Tool space, impedance control



Control loop

The idea is to target a desired motion around which there is



Attractive forces corresponding to adjustable impedance

- Infinite impedance corresponds to pure mobilisation
- Low impedance implies participation of the subject to follow the trajectory.

Another strategy of "Moblization and Interaction"

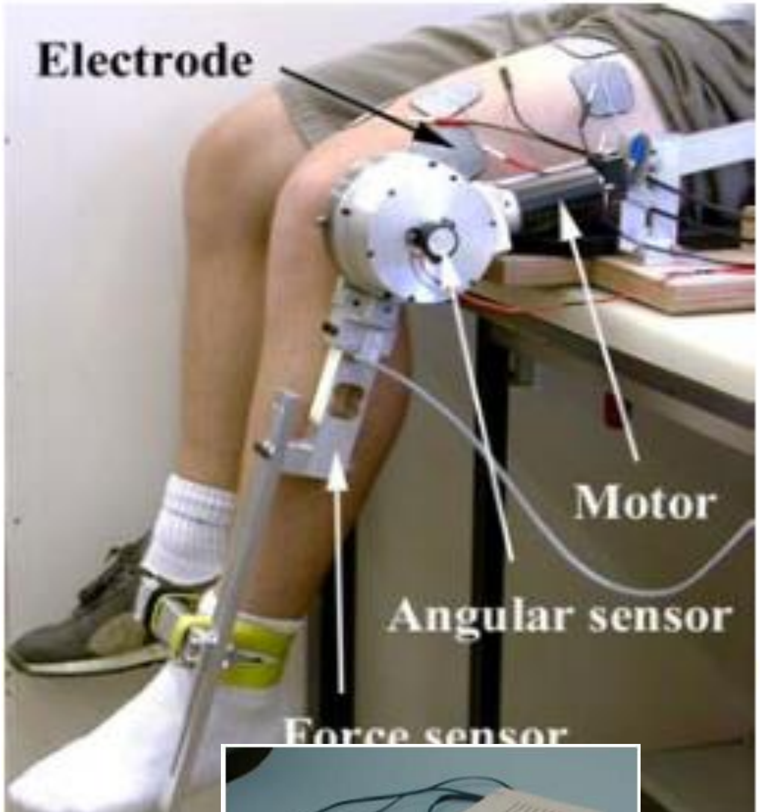
Mobilize and Electrostimulate the muscles

Knee Orthosis

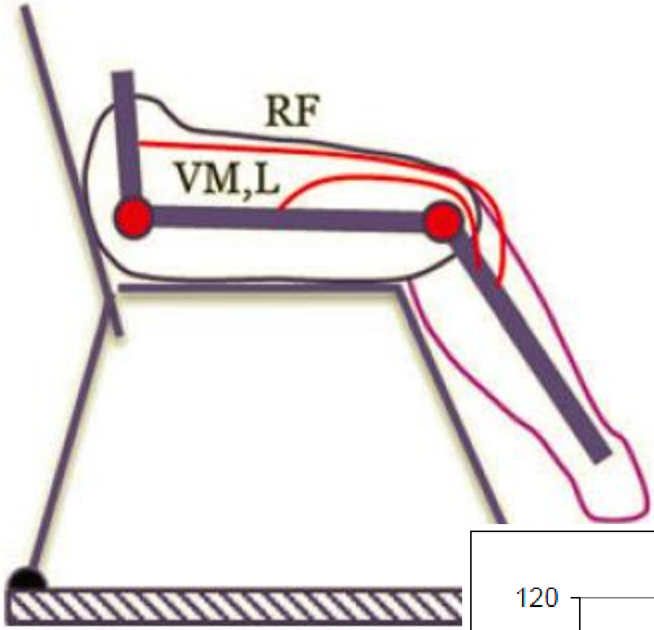
Move + Electrostimulate

<u>Concept:</u>
- Mobilisation

+
- Force control through electrostimulation

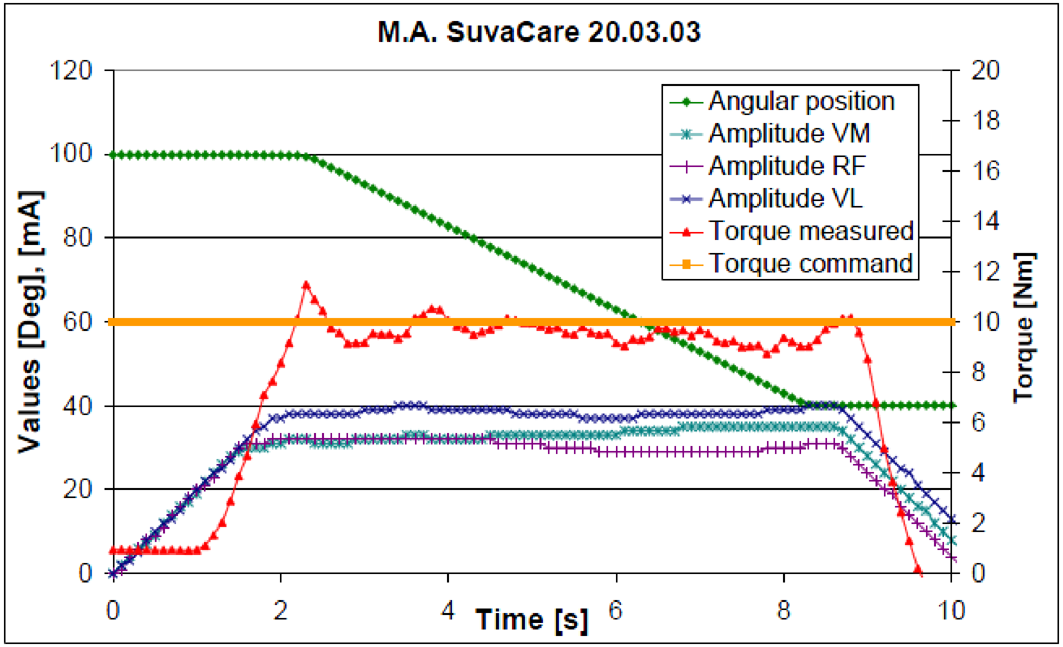


Knee Orthosis Setup



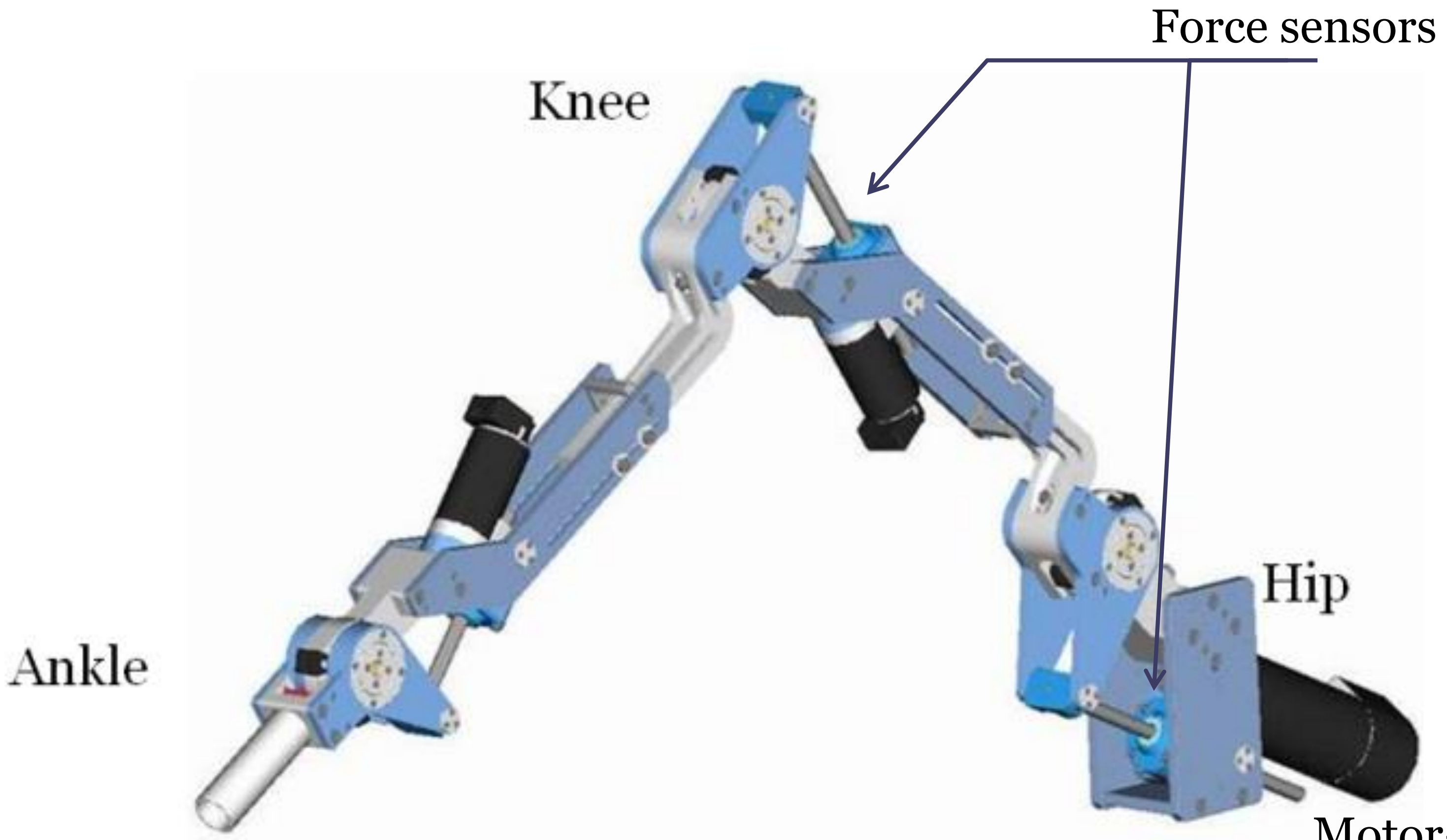
Muscle recruitment for knee extension

Result



The MotionMaker (www.swortec.ch):

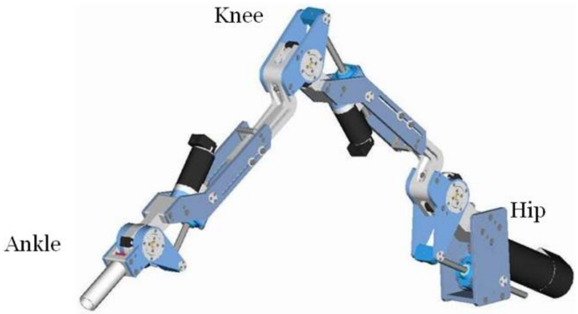
Extension to a 2 Legs orthosis (Right and Left Limb)

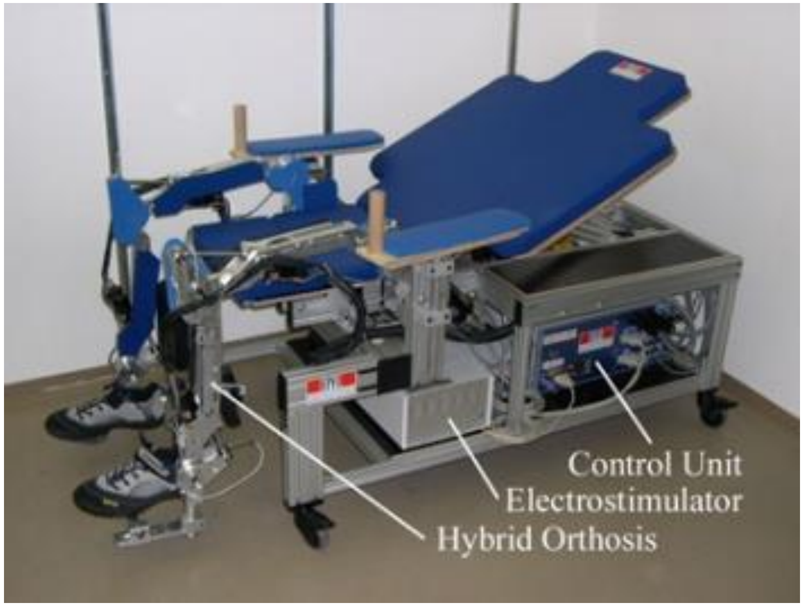


The Motion Maker :

2 Legs orthosis

+ Closed loop Muscle Electrostimulation





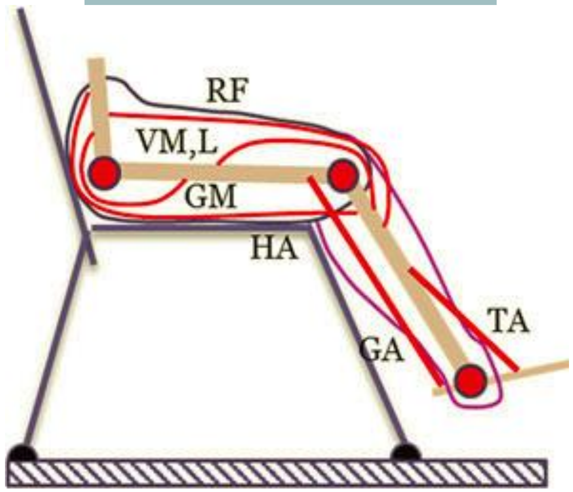
Idea → Concept → Design → Prototype → Industrial Product

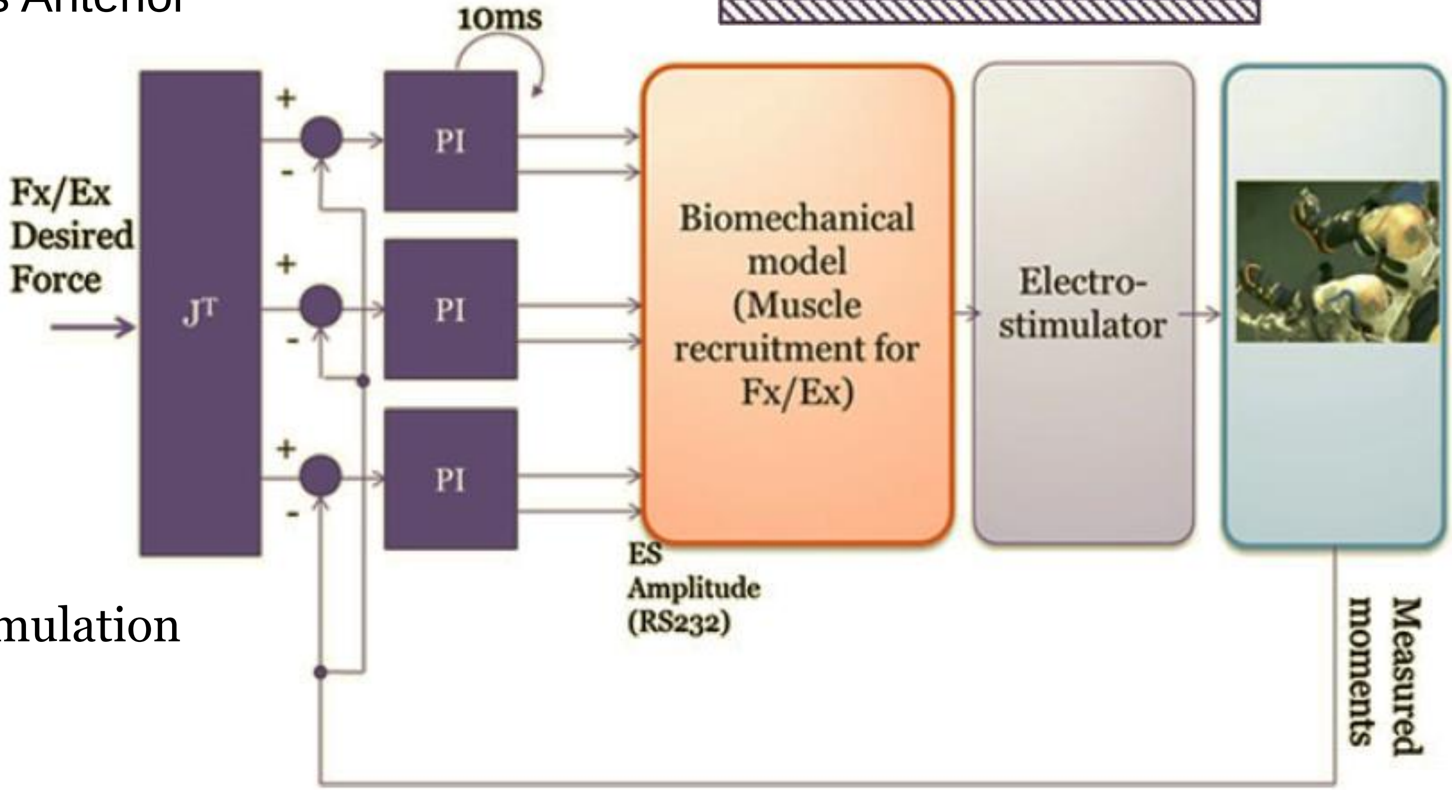
Science to product…..

Closed loop Muscle Electrostimulation

Total of **7 muscles have been used** in the loop:

- RF Rectus Femoris,
- VM, L Vastus Medialis and Lateralis, GM Gluteus maximus.
- HA Hamstring,
- GA Gastrocnemius,
- TA Tibialis Anterior

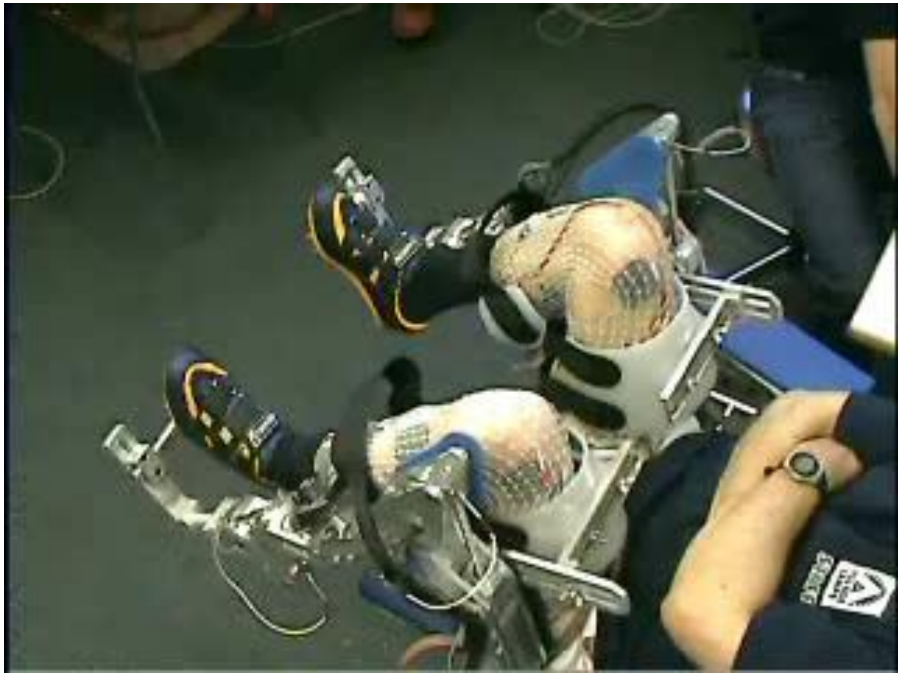




The Electrostimulation Control loop

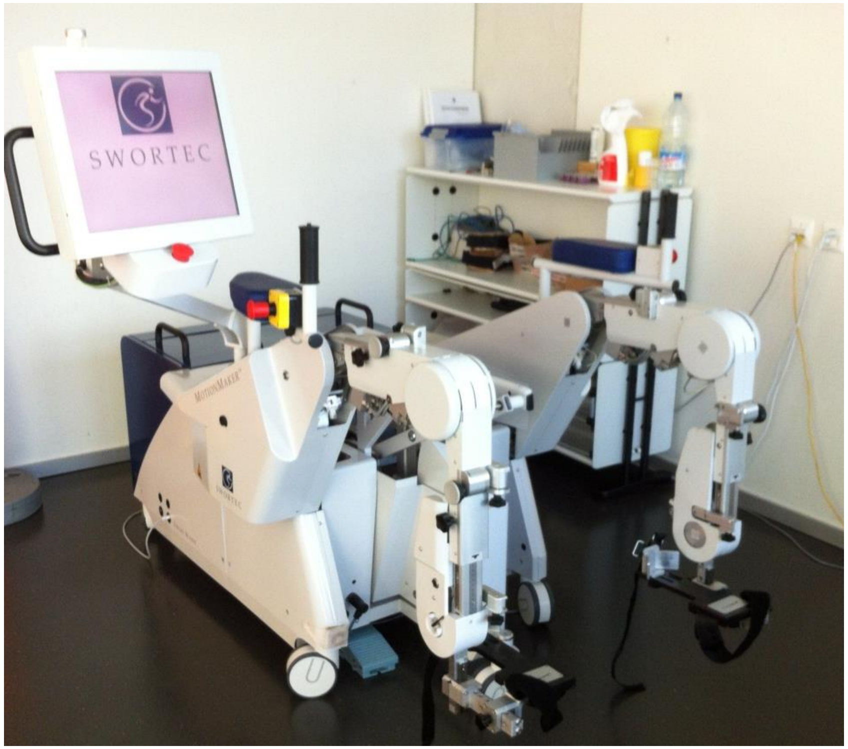
Table 1 Muscle recruitment

Joint	Flexion movement	Extension movement
Hip	Rectus Femoris (RF)	Gluteus Maximus (GM)
Knee	Hamstring (HA)	Vastus Medialis and Lateralis (VM + L)
Ankle	Tibialis Anterior (TA)	Gastrocnemius (GA)



Commercialized MotionMaker

Take Care about the transfer phases



Transfert table

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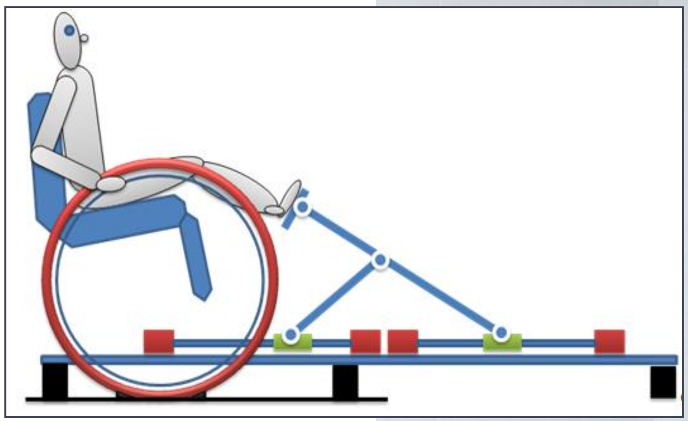
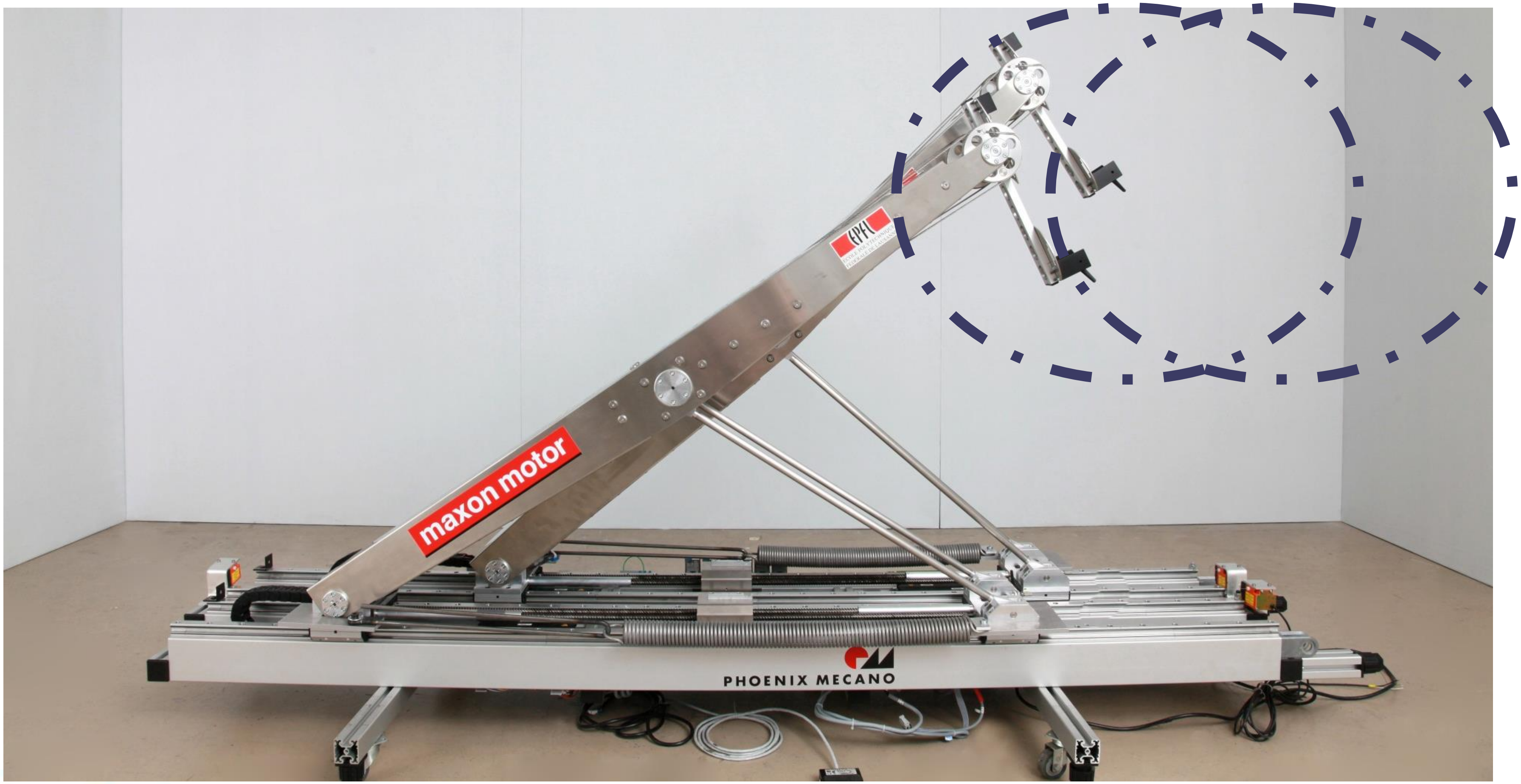
Another concept : The Lambda device



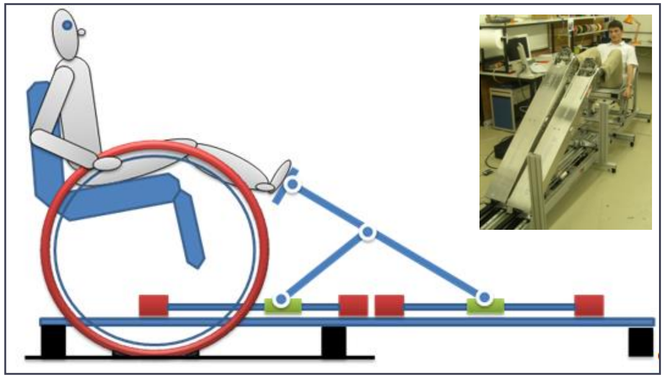
Parallel kinematics

The Lambda : Motivations % MotionMaker

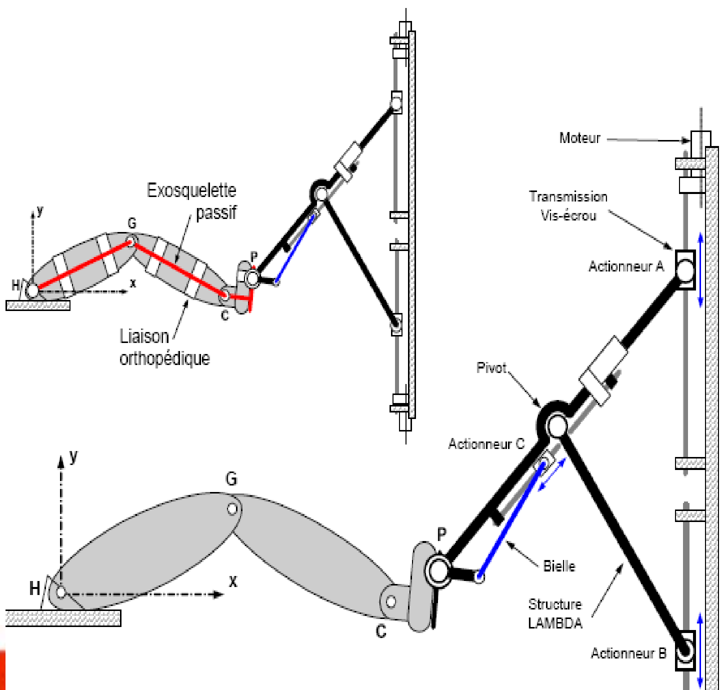
No need of anthropomorphic adjustment



The Lambda : Motivations % MotionMaker

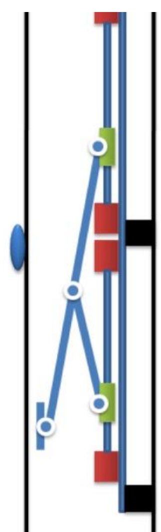


More flexible (different dispositions, adaptable to wheelchairs)

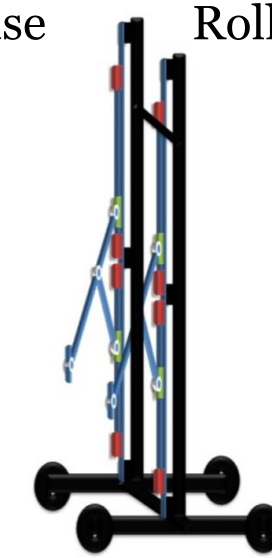


May be verticalized,….

Cabinet use



Roller use



The Lambda : ideas of construction

1-Cable driven Ankle joint

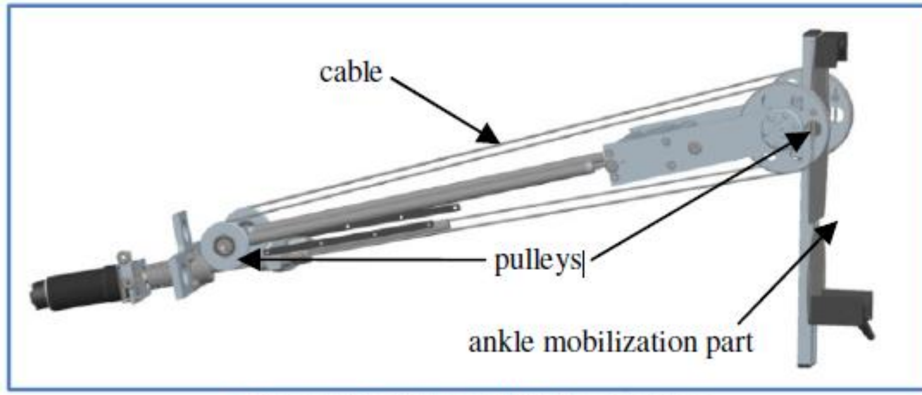


Figure 15, Ankle mobilization system

2- Sensor redundancy for security and axis initialization

3- Springs for gravity compensation and security

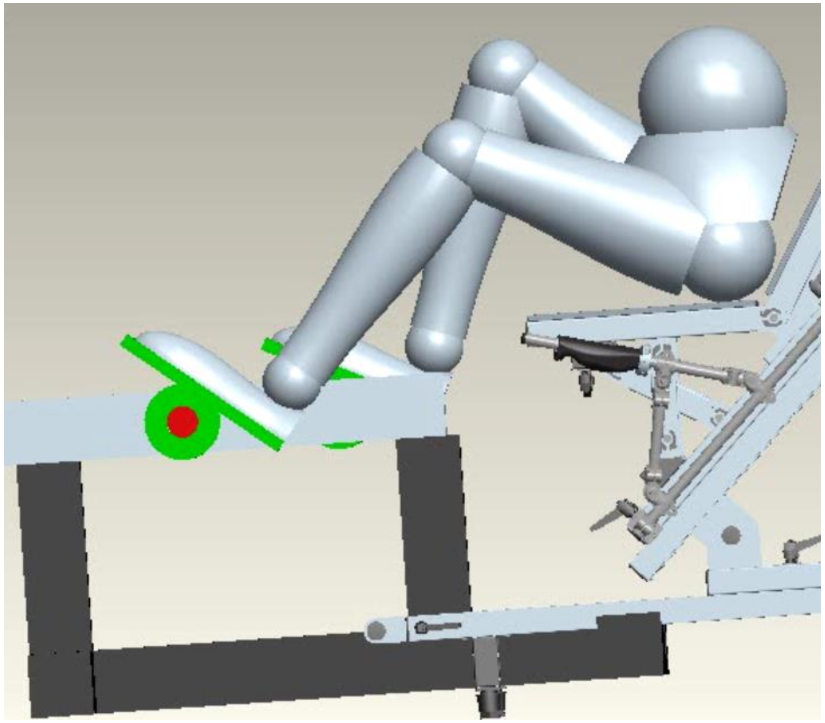
Figure 20, Spring used for the gravity compensation

Movie

A new development : The LegoPress

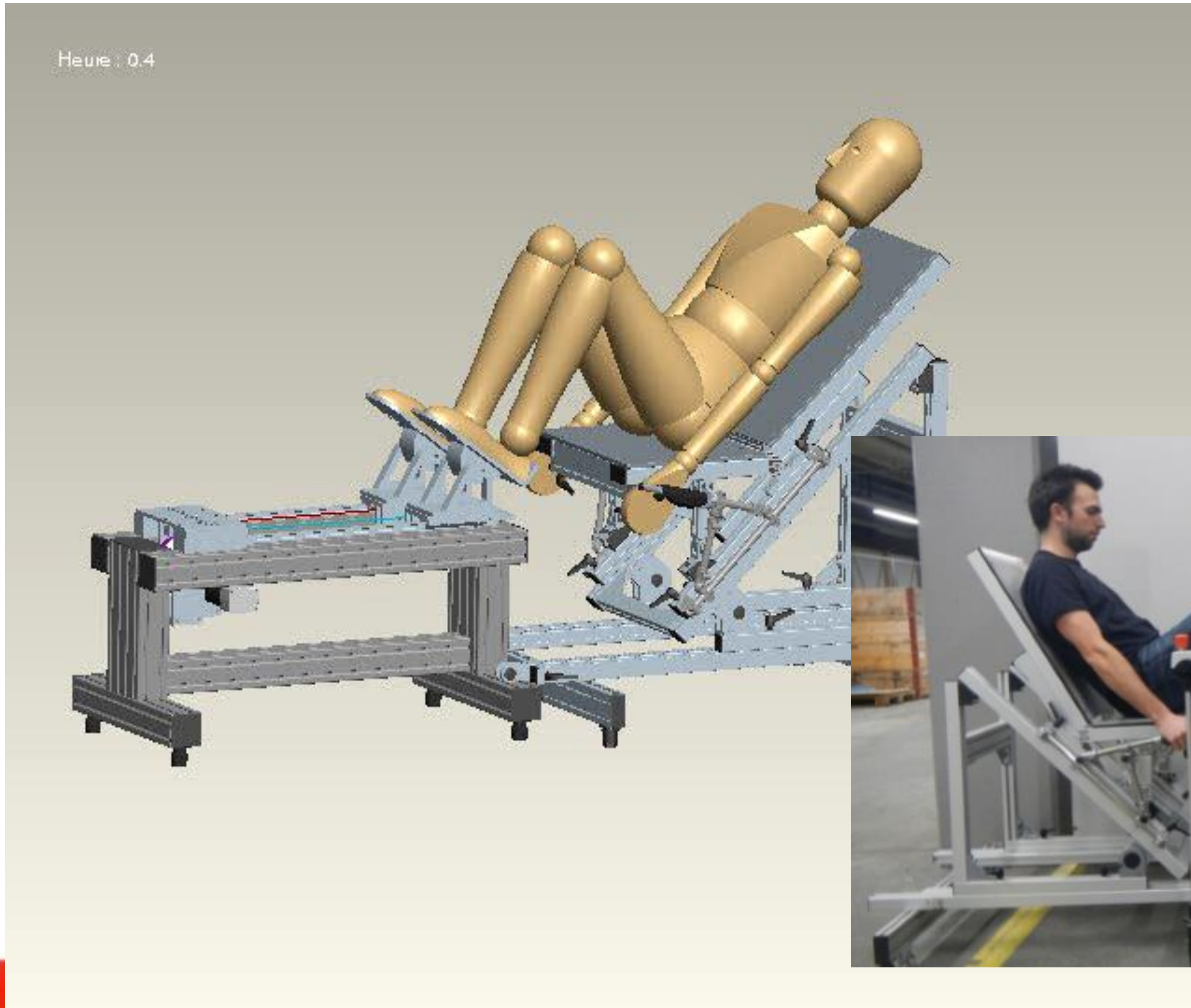
Light Rehabilitation Devices

- Leg Press Movement up to 0.5m
- Alternated Movements
- Synchronized Movements
- Up 0.75 m/s
- Up to 350N / leg
- Equipped with 1 force sensor / leg
- Adjusted Heigh and inclinated chair



The **LegoPress**

Light Rehabilitation Devices



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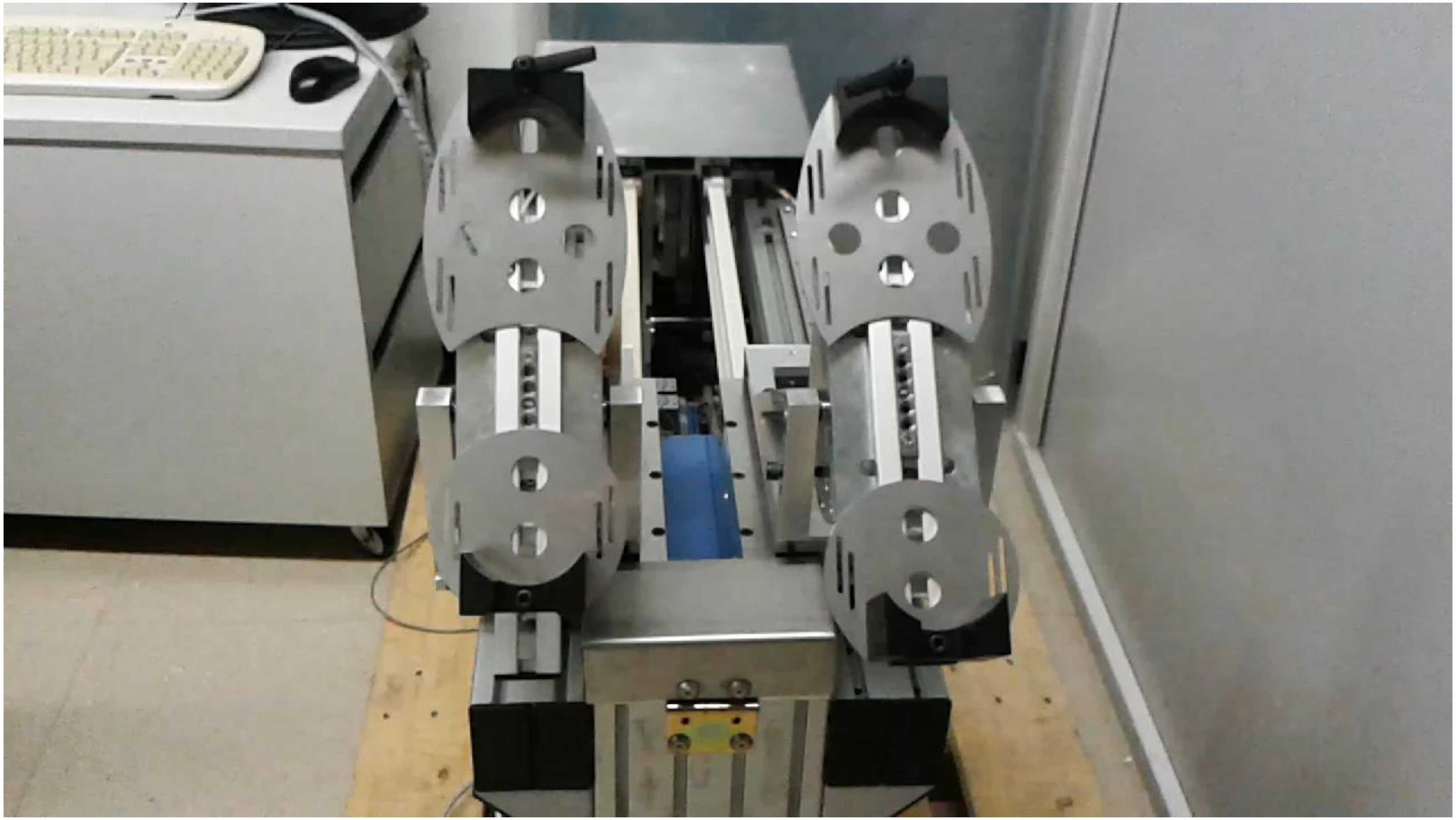
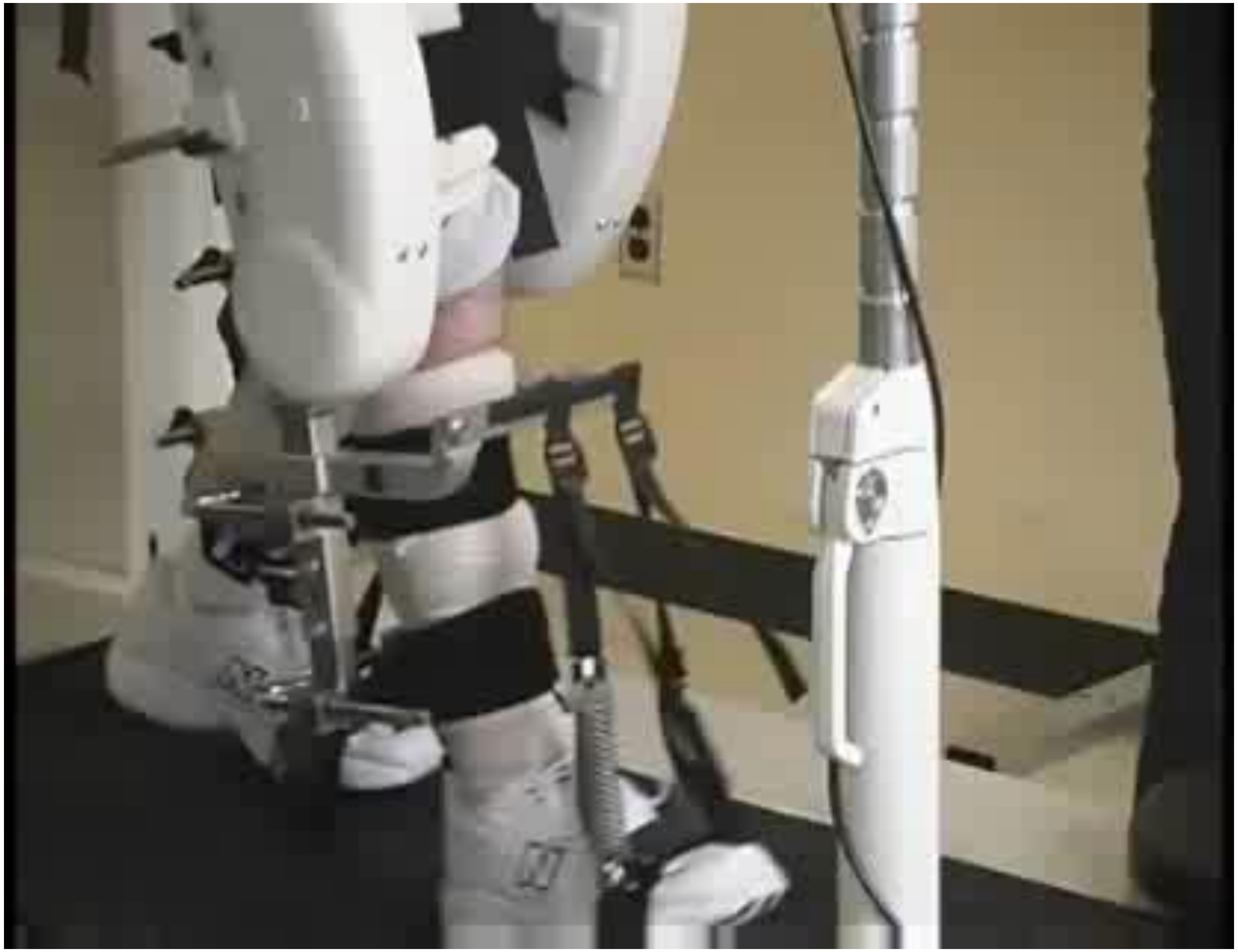
The **LegoPress- Movie**



Part2-
Verticalized Rehabilitation Devices

Verticalized Systems

The Lokomat from HOKOMA, ZH, CH



- Actuated Hip and Knee for each leg.
- Following Ankle joint
- Use of a treadmill
- BodyWeight support
- …
- First prototype that has been sold (more 200 pieces around the world) was totally passive
- An impedance control is also implemented

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Verticalized Systems

The Kineassist from KineaDesign, IL, USA

- Overground Walking
- BodyWeight support
- Pelvis orthosis.
- Fall down safety.

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The WalkTrainer™ developed by EPFL with the Swiss foundation of paraplegics and the company Swortec SA, VS, CH

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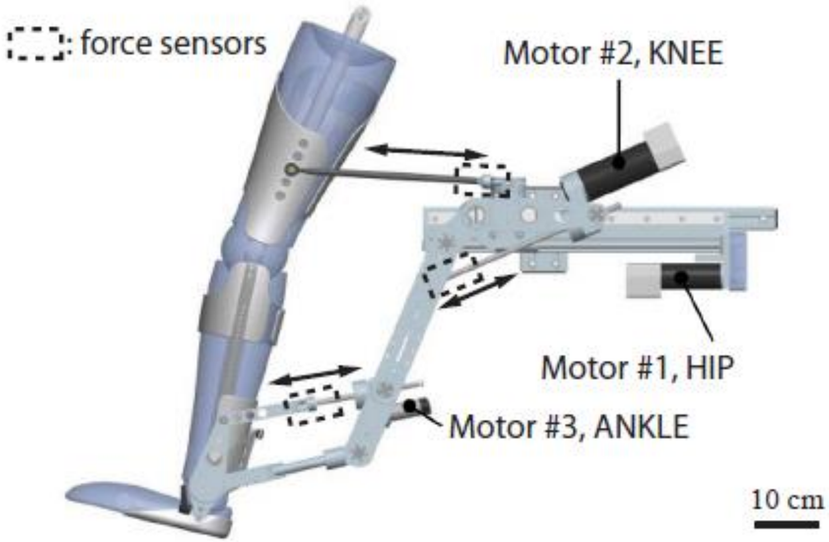
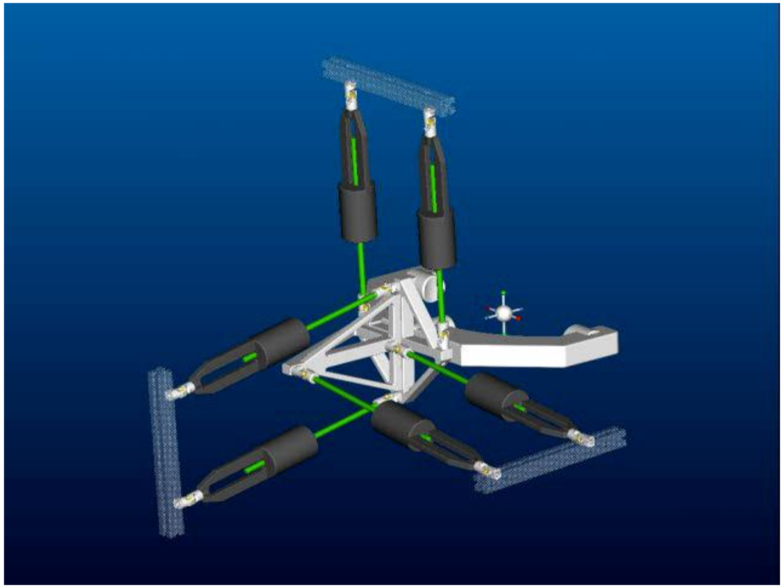
Leg Orthosis and leg interface



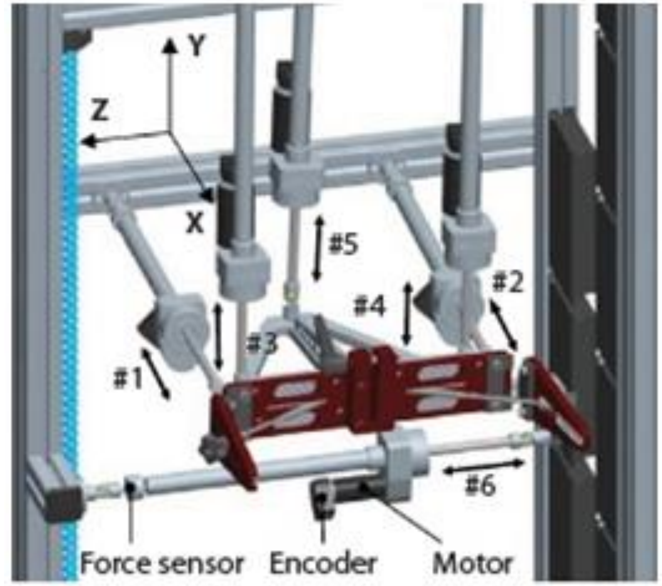
(a) Schematic view of the leg orthosis.

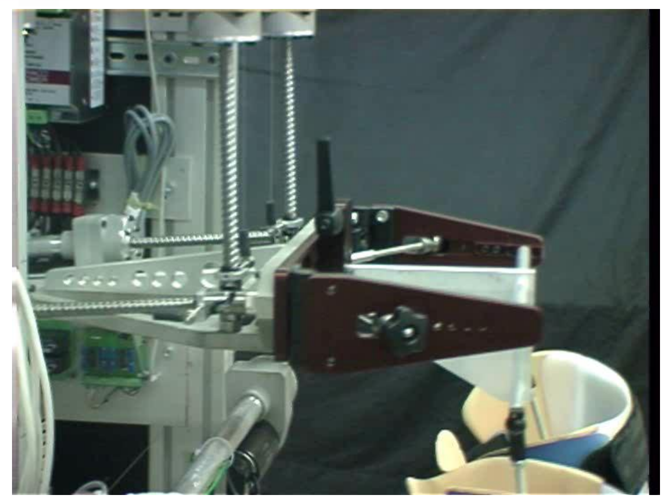
(b) Realization of the leg orthosis.

Pelvic Orthosis



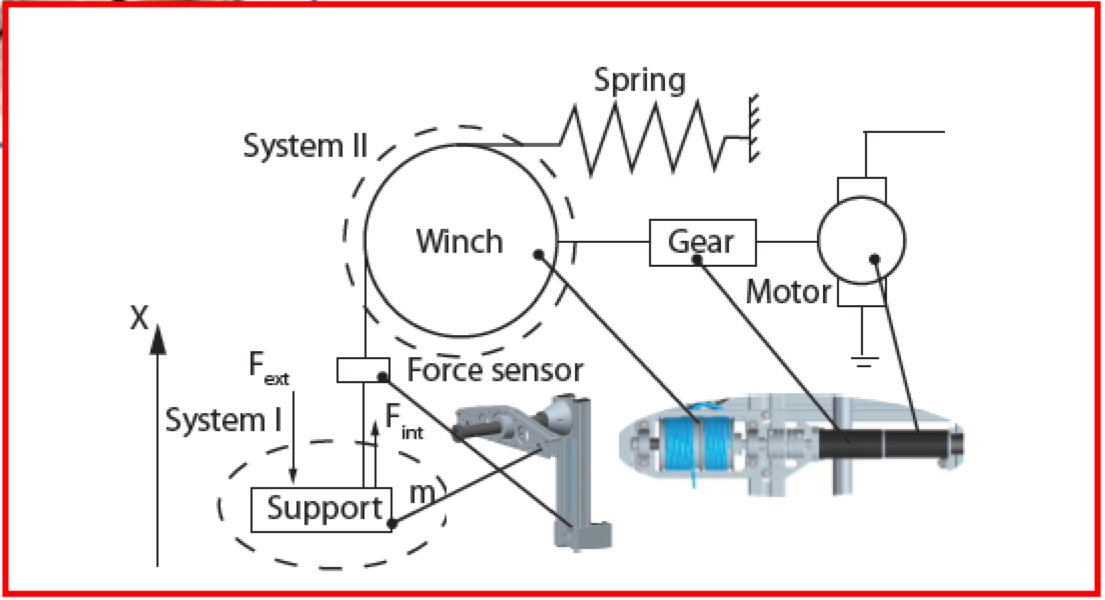
2 x 2 x 2 Kinematics





3 x 2 x 1 Kinematics

Body Weight Support



Clinical trials - Preparation

(a) Electrode placement.

(b) Exoskeleton placement.

(c) Harness fixation.

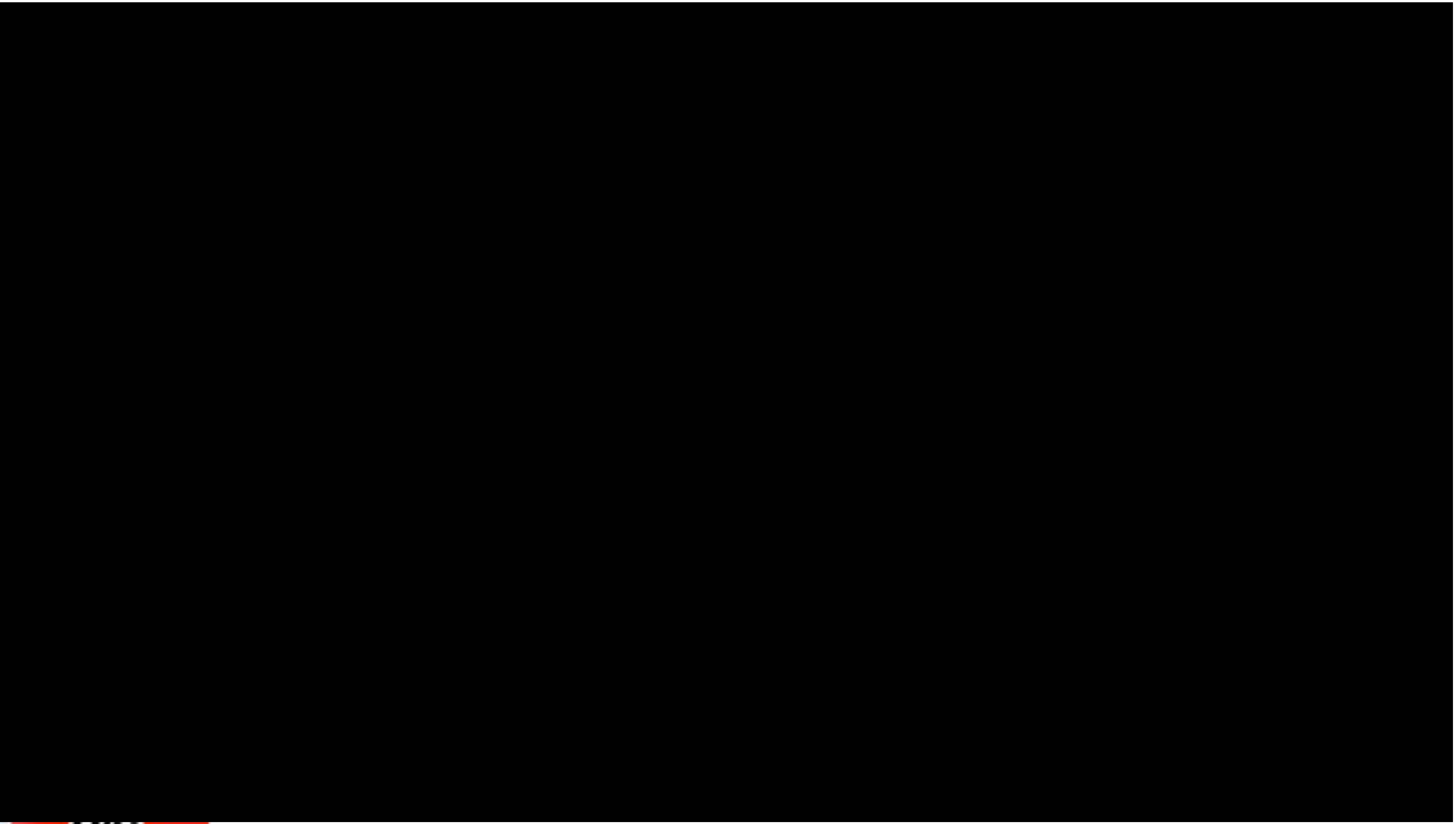
Clinical trials - Transfer

(a) Installation in the Cigogne.

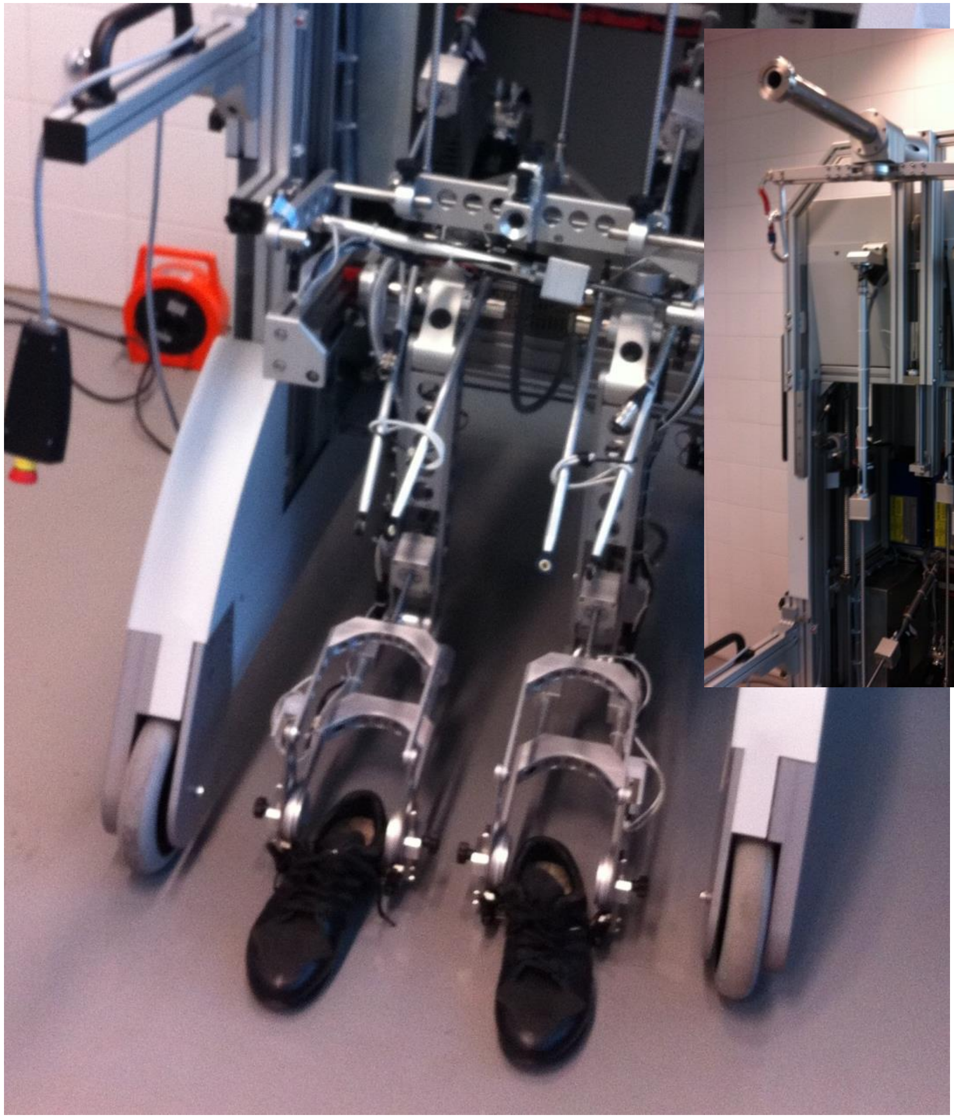
(b) Transfer to the WalkTrainer.

(c) Fixation to the WalkTrainer.

The WalkTrainer : **The Movie**



WalkTrainer : The product



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Part 3-
Walk Assistance devices

Walk Assistance

- Soya TAKAGI (Toyota)

Independant Walk Assist

Patient Transfer

Walk Training Assist

Balance Training Assist

Force amplification



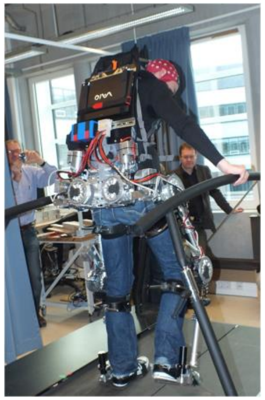


Nom	**HULC**	**Sarcos/ Raytheon**	**Kawasaki Power Assist Suit**	**Panasonic Power Loader Light**	**HERCULE**
Origine	U.S.A	U.S.A	Japon	Japon	France
Secteur	Militaire	Militaire	Industrie - développement	Industrie - développement	Militaire
Capacités	Supporte 90kg Assiste la marche/ course jusqu'à 16km/h	Supporte 90kg	Soulever 40kg	Support d'une partie de la personne + 60kg de charge dorsale	Soulever 40kg
Technologie de contrôle	Capteurs de position et force	Capteurs de forces	Capteurs de force	Capteurs de force	Capteurs de force
Poids	24 kg	68 kg	?	38 kg	25 kg

- Paraplegic assistance





Nom	Ekso	ReWalk	REX	Indego	NASA X1	MindWalker
Origine	U.S.A	Israël	NZ	U.S.A	U.S.A	Europe
Secteur	Industrie - commercialisé	Industrie - commercialisé	Industrie - commercialisé	Recherche	Recherche	Recherche
Vitesse	1.6 km/h	3 km/h	0.18 km/h	0.8 km/h	-	-
Stable	Non	Non	Oui	Non	Non	Non
Poids	23 kg	18 kg	39 kg	12 kg	25 kg	-
Technologie	Capteurs de position et moteurs électriques					
				+Électrostimulation		
Contrôle	Commande + positionnement	Commande + positionnement	Joystick	Commande + positionnement	-	Capteurs EEG

Walk Assistive devices for healthy

Nom	Cyberdyne HAL	Honda Weight Support Assist	Honda stride management	EXPOS
Origine	Japon	Japon	Japon	Korea
Secteur	Recherche/Industrie – essais cliniques	Industrie – développement	Industrie – essais cliniques	Recherche
Poids	23 kg	6.5 kg	2.8 kg	< 3 kg sur le patient
Capacités	Assiste les mouvements de la marche	Applique une force inversement proportionnelle à la hauteur d'assise	Assiste la marche en corrigeant la cinématique	Assiste les mouvements de la marche, hardware embarqué sur un déambulateur
Contrôle	EMG + capteurs de position + capteurs de pression	Capteurs de position	Capteurs de position	Capteurs de position + de contraction musculaire

Walk Assistance

The HAL device from Cyberdyne

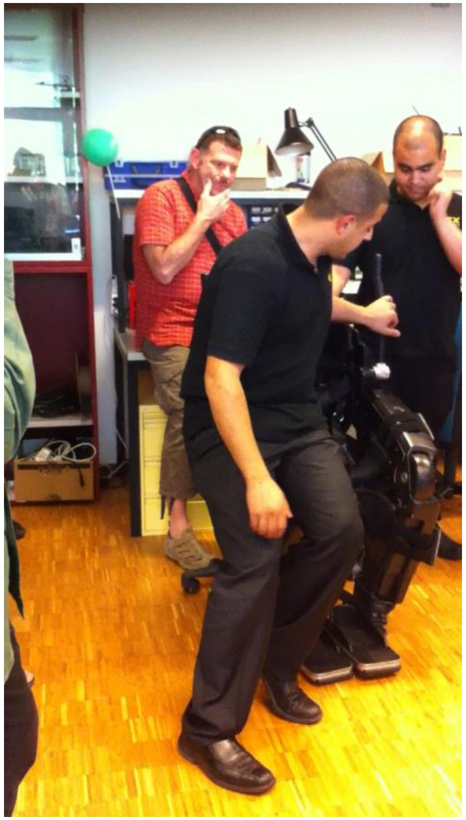
Walk Assistance

The REX device from Rex Bionics

Walk Assistance

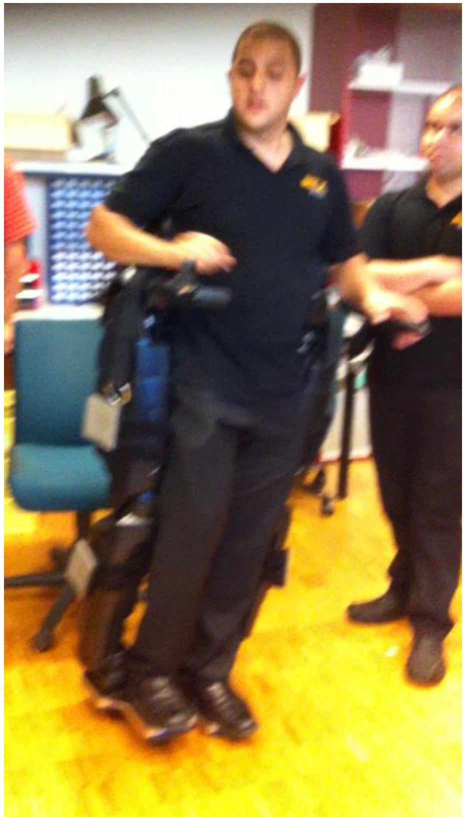
The Rex device from Rex Bionics

1-Transfert



2-Walking

3-Stability



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Walk Assistance

The EKSO

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Walk Assistance

The EKSO

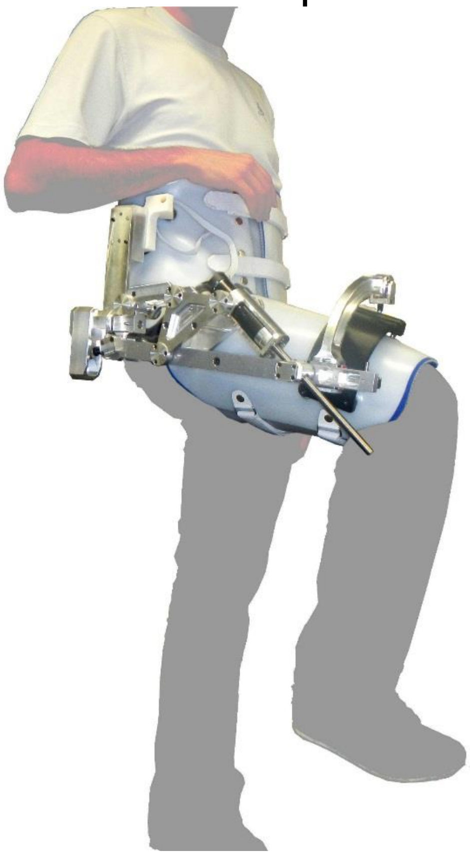
EWO™ A new Elderly Walking Orthosis

PhD student (Current Project), **Jeremy Olivier**

robotics
Swiss National Centre of Competence in Research

Current development concerns the HIP orthosis

- Totally 3 DOF Orthosis
- Actuated in the sagittal plan
- Free in the other DOF



Screw transmission

Double Differential transmission

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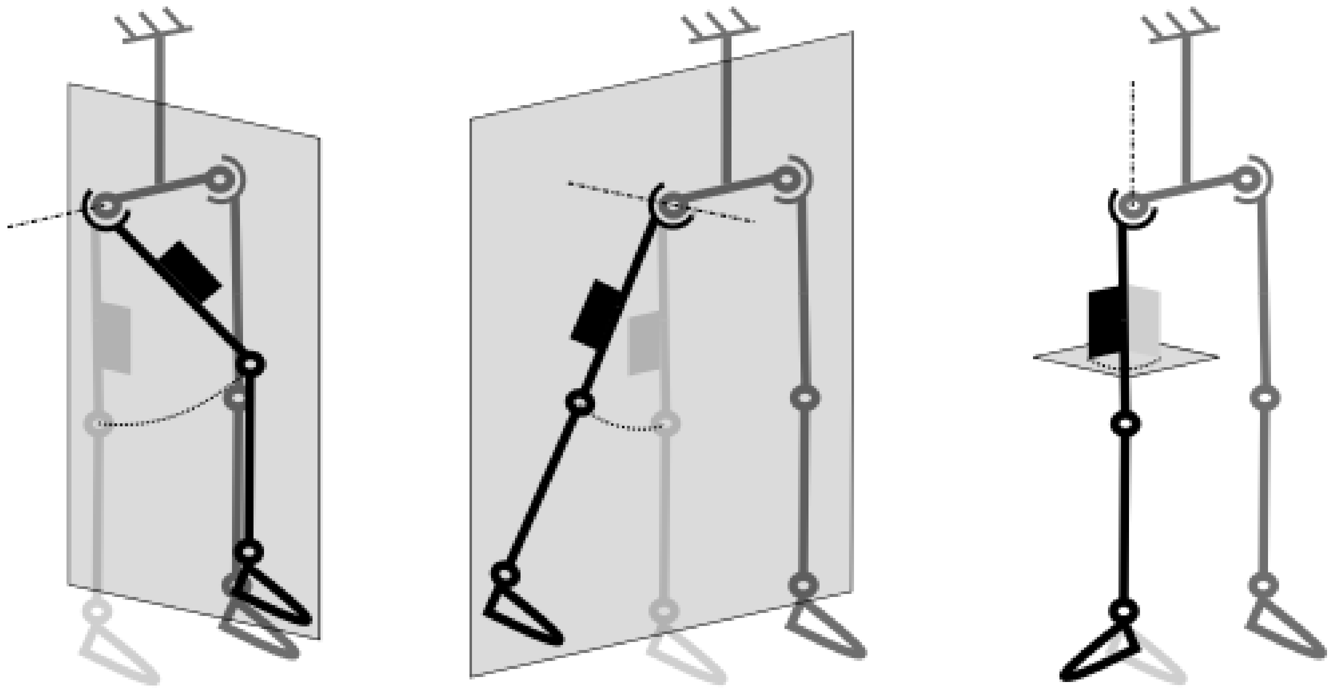
Biomechanical considerations

- Hip is a spherical joint



Torque and velocity requirements

- RMS torque during level walking: ~ 0.3 Nm/kg
- Maximum angular velocity: ~ 140 deg/s
- Peak torque during sit-to-stand transitions: ~ 1 Nm/kg (when the hip flexion angle is around 70 deg)

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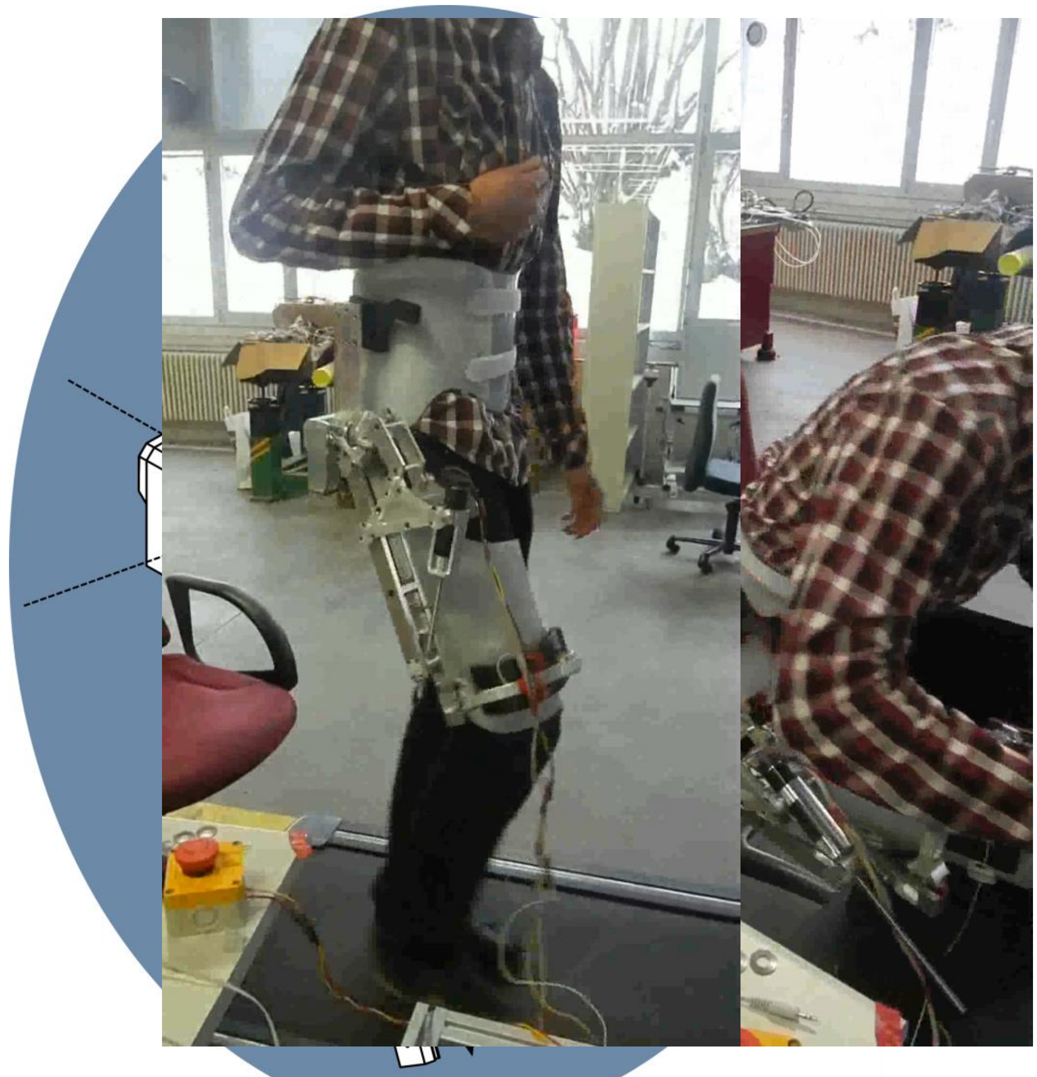
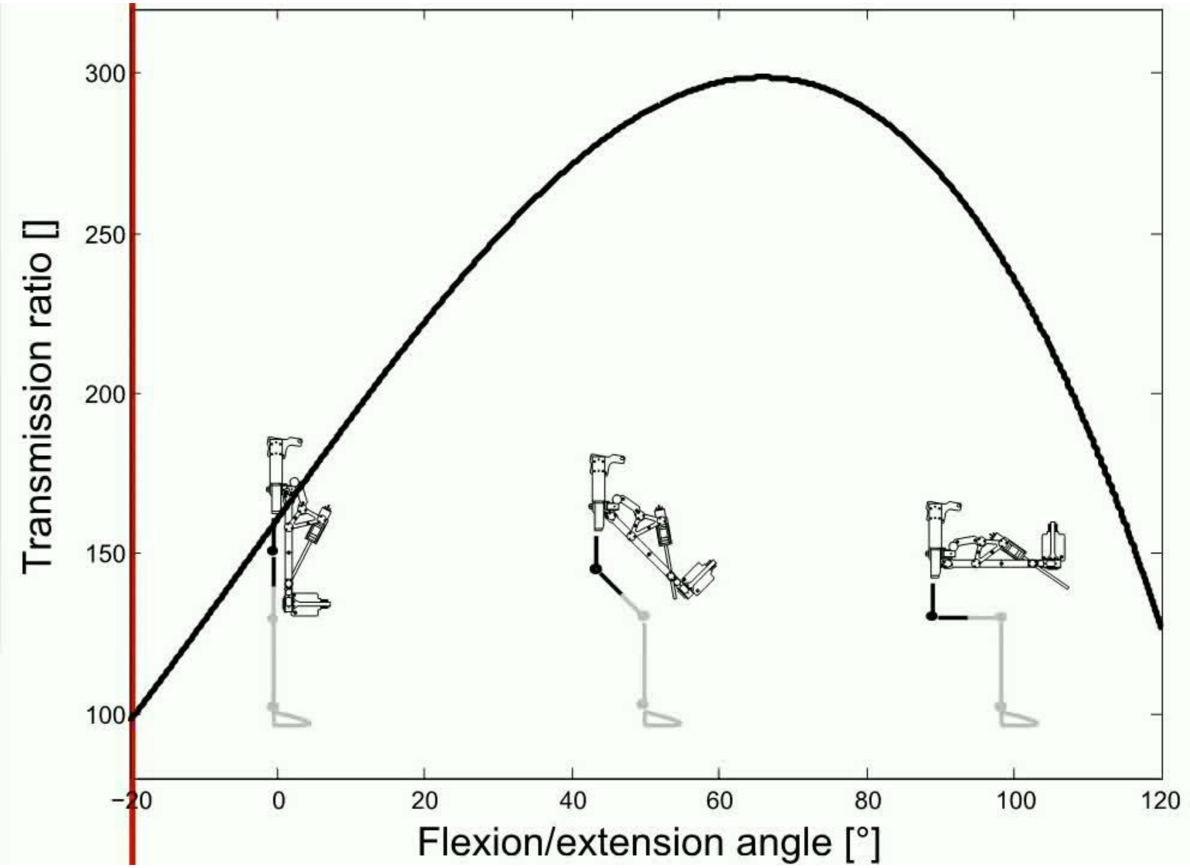
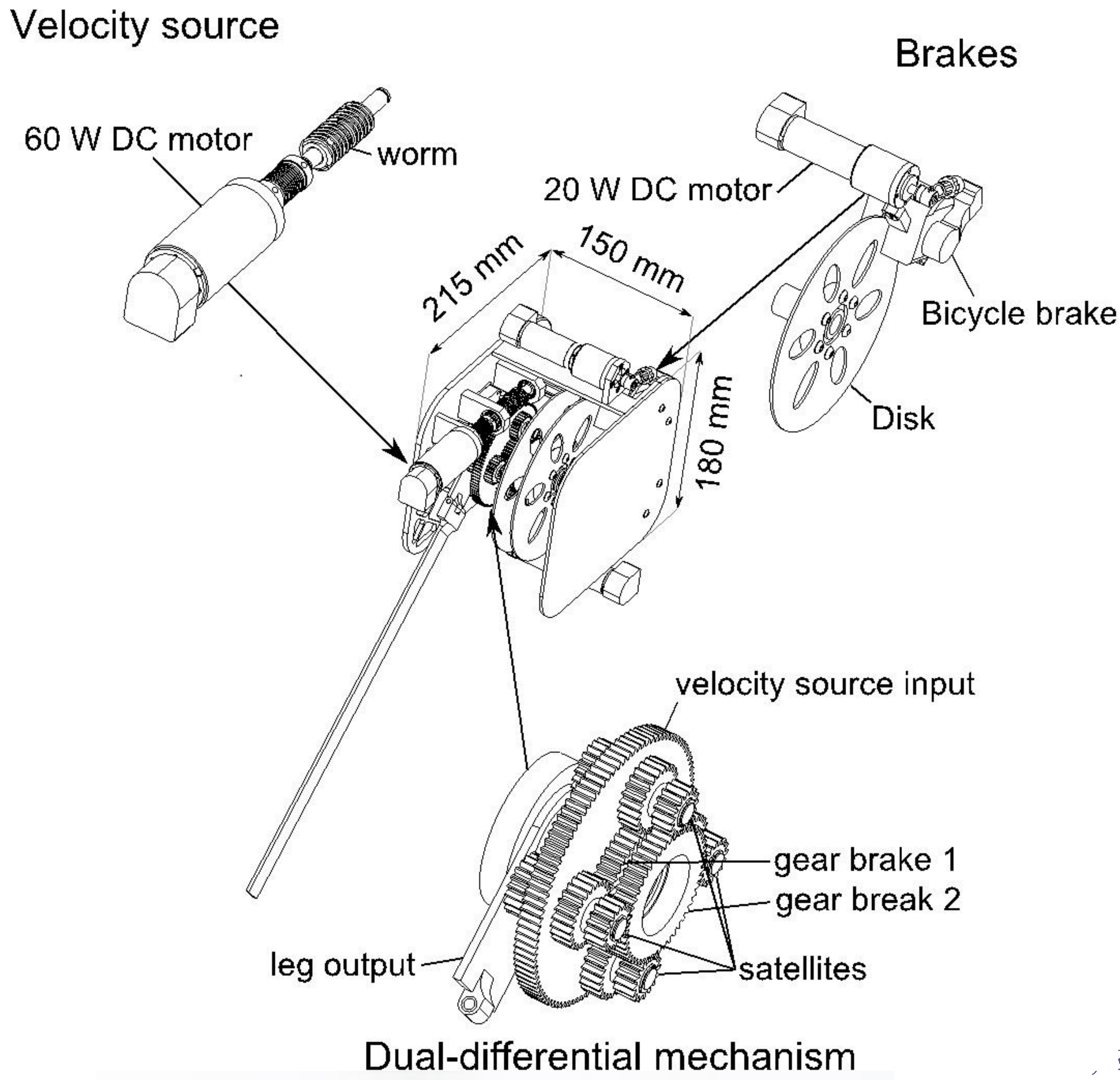
Screw-driven orthosis



Amplification mechanism



Double-Differential



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