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Experiences and devices in robotic rehabilitation of the upper limb and hand

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Maciejasz *et al. Journal of NeuroEngineering and Rehabilitation* 2014, **11**:3
http://www.jneuroengrehab.com/content/11/1/3

JOURNAL OF NEUROENGINEERING AND REHABILITATION

REVIEW Open Access

A survey on robotic devices for upper limb rehabilitation

Paweł Maciejasz[1,2,3], Jörg Eschweiler[4*], Kurt Gerlach-Hahn[5], Arne Jansen-Troy[4] and Steffen Leonhardt[5]

ABOUT 140 DIFFERENT DEVICES HAVE BEEN REPORTED FOR THE UPPER LIMB!!!!!!!

They are classified only according to the joints trained (shoulder, elbow, wrist, hand)

This classification do not provide information about their use in clinical practice where the question is: *which device for which patients?*

CLASSIFICATION

Interactive Robotic Devices for Neuro-Rehabilitation:

To provide and to accelerate brain or spinal cord plasticity and recovery, over time in sub-acute phase

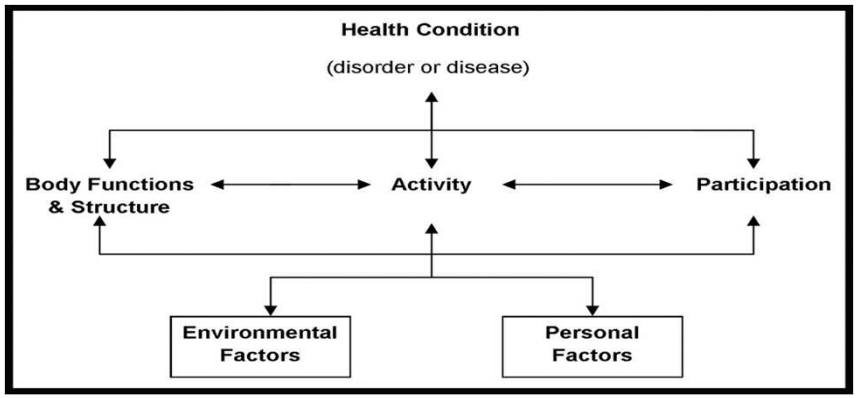
To modify the pathological pattern developed in chronic phase

The target is body function and structure in the framework of I.C.F.

Assistive Robotic Devices:

To augment the capabilities of an injured individual in performing activities of daily living even if without producing a recovery effect

The target are activity and participation in the framework of I.C.F.



Interactive Robotic Devices for Neuro-Rehabilitation

- Close physical interaction between a disabled patient and a powerful source of mechanical stimulation
- Safety without restrictions on the amount of allowable forces that can be generated by the system

ROBOT

Passive devices:

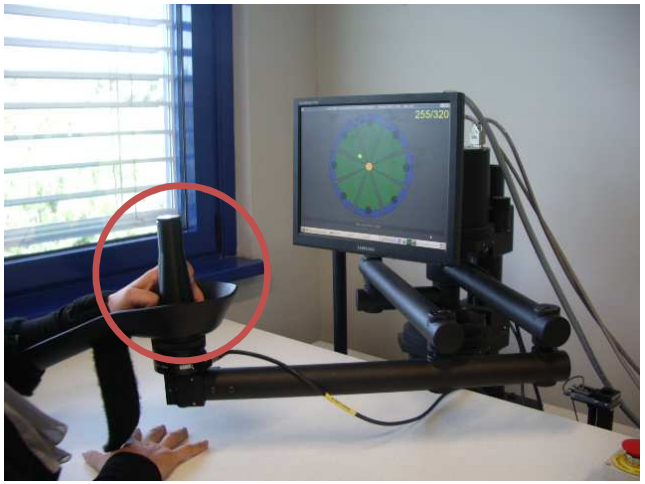
- they are not equipped with motors.
- They are moved directly by the subject which is active
- The target could be orthopedic patients, but also mild and moderate neurologically impaired subjects

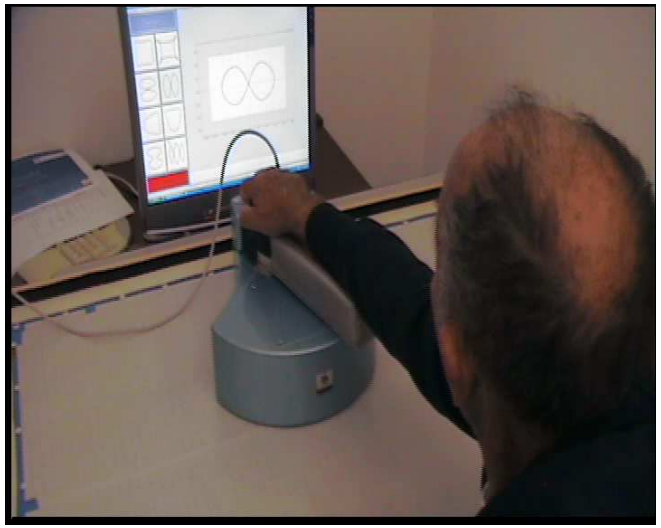
ACTIVE ROBOT
equipped with motors,

- **Exoskeleton-like machines:** The machine is designed so that the trajectories of its end-effector and of all its joints are coincident to that of the natural limb in the operational space and in the joint space.
- They are weareable systems providing the same movement of the patients with the same degrees of freedom of the joints involved in the rehabilitative treatment

ACTIVE ROBOT
equipped with motors,
END EFFECTOR

- ❑ The contact between the patient and the machine is only at the end-effector, through a purposive mechanical interface (handle)
- ❑ The machine is designed so that the trajectory of its end-effector is coincident to that of the natural effector (hand/foot) in the operational space
- ❑ The patient is expected to exploit her/his own synergies at joint level to follow a trajectory in the operational space





CONTROL SYSTEMS

- IMPEDANCE CONTROL:
  - Low impedance of actuators and low friction.
  - The exerted force cannot be very strong

- ADIMITTANCE CONTROL:
  - Heavier Actuators required.
  - Instability.
  - Powerful motor
  - Safety problems
  - Strong forces can be exerted.

Interactive Robotic Devices for Neuro-Rehabilitation

Type of assistance:

Assisted Therapy: Robot is active and the patient is passive

Assisted as Needed Therapy: Robot help the patient to reach the target

Error enhancement: Robot “disturbs” the patients during the reaching

Resistive Therapy: the robot may damp out or oppose the mechanical power generated by the patient to make the tasks

Interactive Robotic Devices for Neuro-Rehabilitation

Type of Tasks:

Tasks in “Natural Environment”:

Tasks in “Virtual Environment”

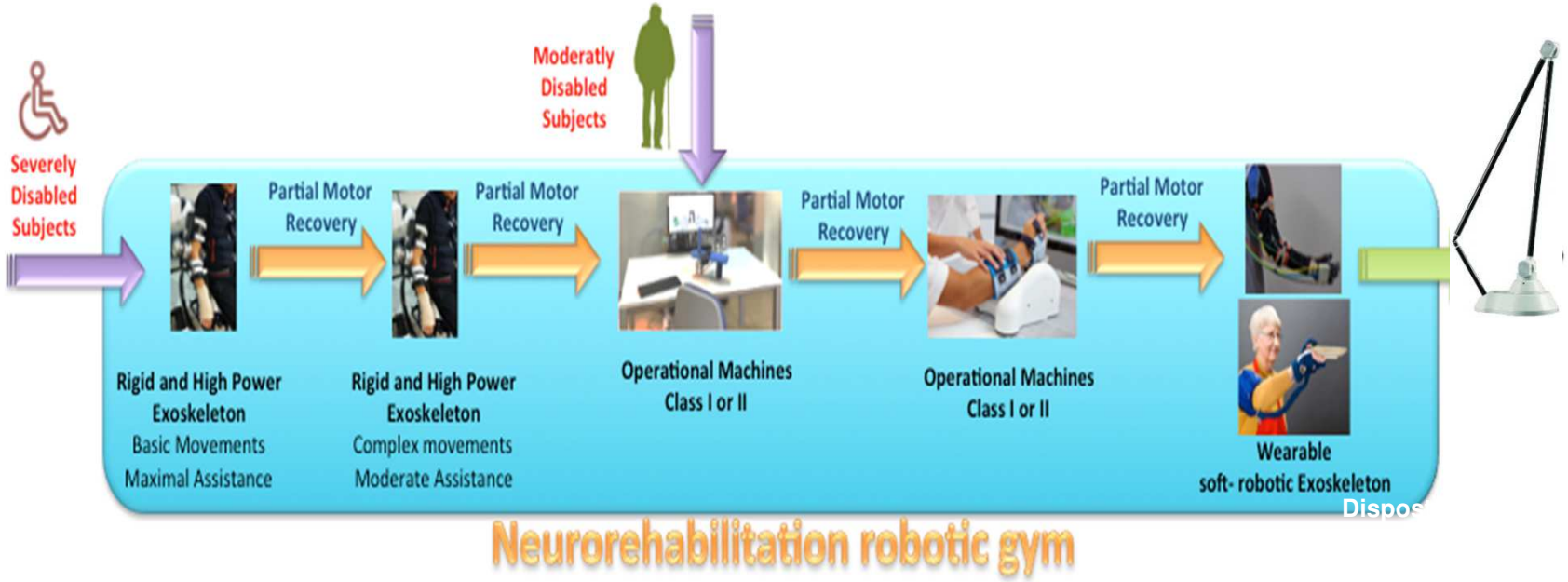
Programmable vs not programmable tasks

Interactive Robotic Devices for Neuro-Rehabilitation

PAREMETERS RECORDED

- Kinematic parameters
- Dinamic parameters

RONDA PROJECT



Many robotic devices able to provided specific exercise in order to really tailor the task to patient who, during the treatment, can change the device and not only exercises

RONDA PROJECT:
Neurorehabilitation Robotic Gym

Different Device

- **Exoskeletal device able to provide higth forces for very severe impaired patients**
- **Exoskeletal device with low friction but able to provide lower forces for less severly disable patients**
- **End effector device, normally planar, for less severe impaired patient able to use their synergies**
- **Passive device for patients which are able to activily move their upper limb**

All devices can provide a virtual visual feedback or they ask to the subject to move in "natural" environment performing goal direct movement.

Interactive Robotic Devices for Neuro-Rehabilitation

The question is:

How and Who assess the patients in order to be addressed to the tailored device?

The answer is:

Robotic devices themselves

Rehabilitation vs Assessment

To develop robotic devices able to assess not only kinematic parameter or force exerted by the patient in the same movement directions, but also the force exerted AGAINST the movement direction due to spasticity

i.e. During an extension elbow movement which is the force against the extension?

In this way we can have a technologically advances assessment of spasticity (MAS) end Range of Motion (ROM)

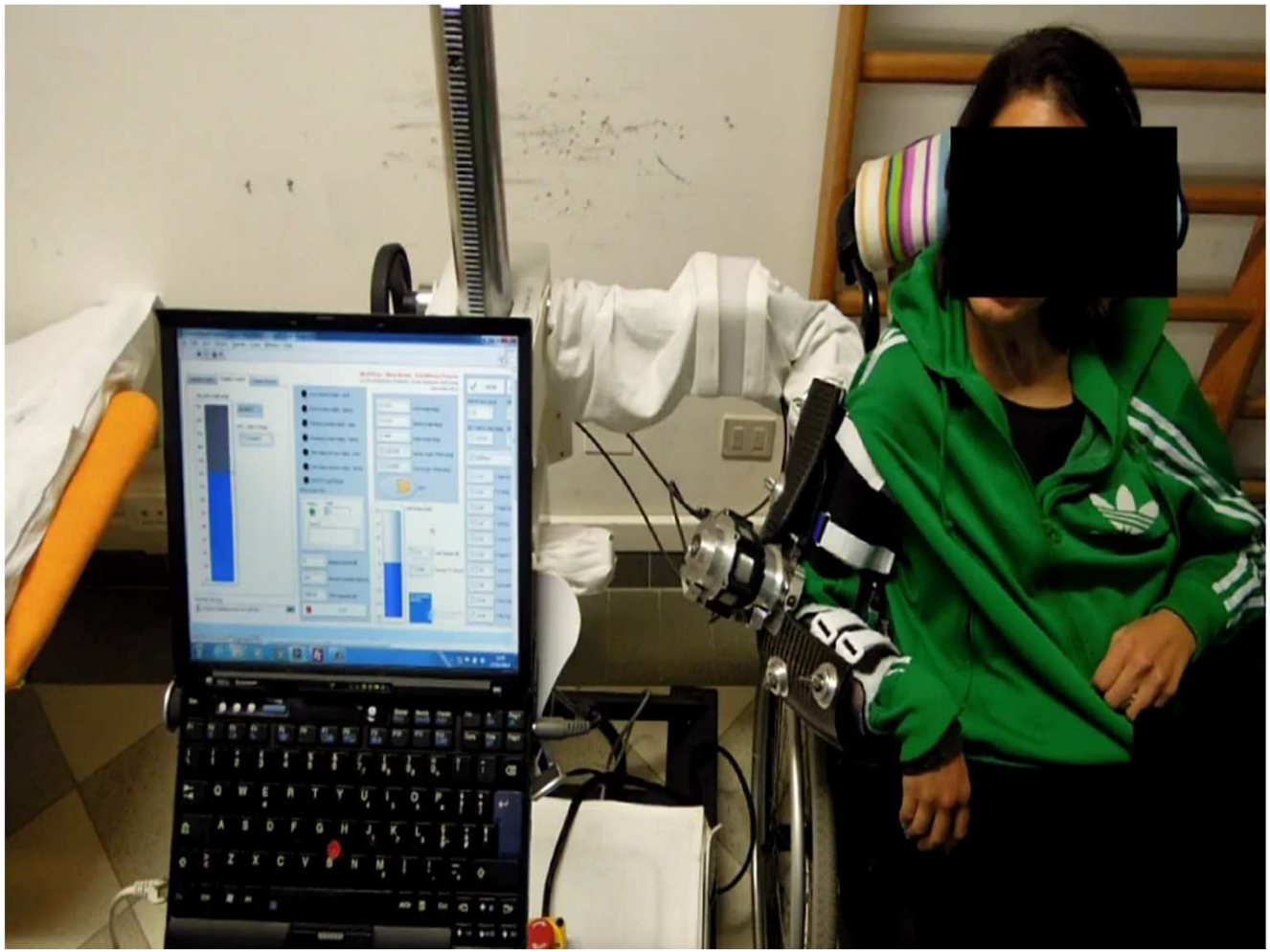
NEUROEXSOS ELBOW MODULE

The system is able to record the force against the movement required exerted by the patient.

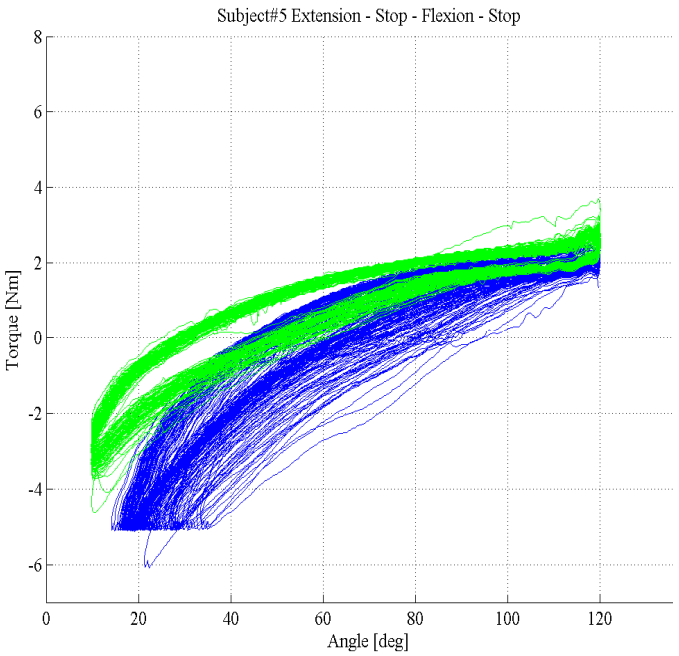
It is able to detect, during an elbow extension, which is the force that spastic muscles exerted in flexion direction.

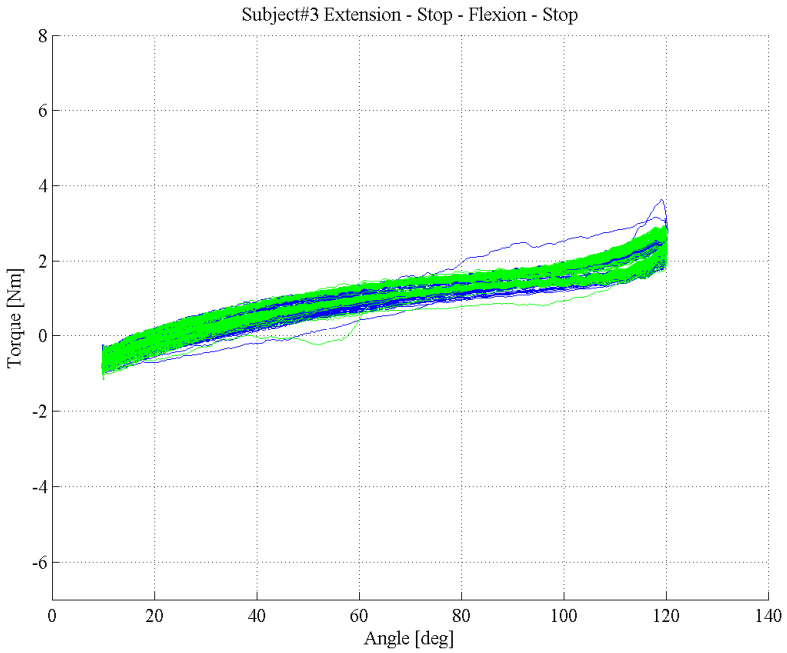
A threshold can be fixed and when the patient reach the threshold fixed, the device stop the extension and start the flexion. When the force come back under the threshold the system start again the extension and so on.

NEUROEXSOS ELBOW MODULE



Objective effectiveness evaluation of botulin toxin injection





Torque (MAS) end position (ROM) at the first day after injection (blue) end at the last (green)

Phase-2 clinical study “Rehabilitation”

- Targeted patients
  - Post-stroke in acute phase (25±10 days after event)
  - Right arm spasticity: unnaturally flexed/pronated elbow posture
  - No other therapies than NEUROExos
- Responsible/Reference:
  - Auxilium Vitae (Volterra, Pisa – Italy)
  - Federico Posteraro (MD), N. Vitiello (PhD), S. Mazzoleni (PhD)
- Observational study on a 17-subjects population
  - 10 days of passive motion through NEUROExos, 45 min session duration, several repetition of the same task
- Aims
  - Suggestions for spasticity definition/measurability
  - Differences in spasticity evaluation between NEUROExos measurements and clinical scale assessment
- Notes:
  - Study has been approved by Local Ethical Committee and Italian Minister for Health
  - NEUROExos can be easily replicated for multi-center studies, and complies with EU Regulations for Class IIa Medical Devices (IEC EN 60601-1:2007,EN ISO 14971:2012)

Crea et al., Frontiers in Neuroscience, 2017,

Outcomes

- **NEUROExos spasticity indexes**

1. Maximum extension torque

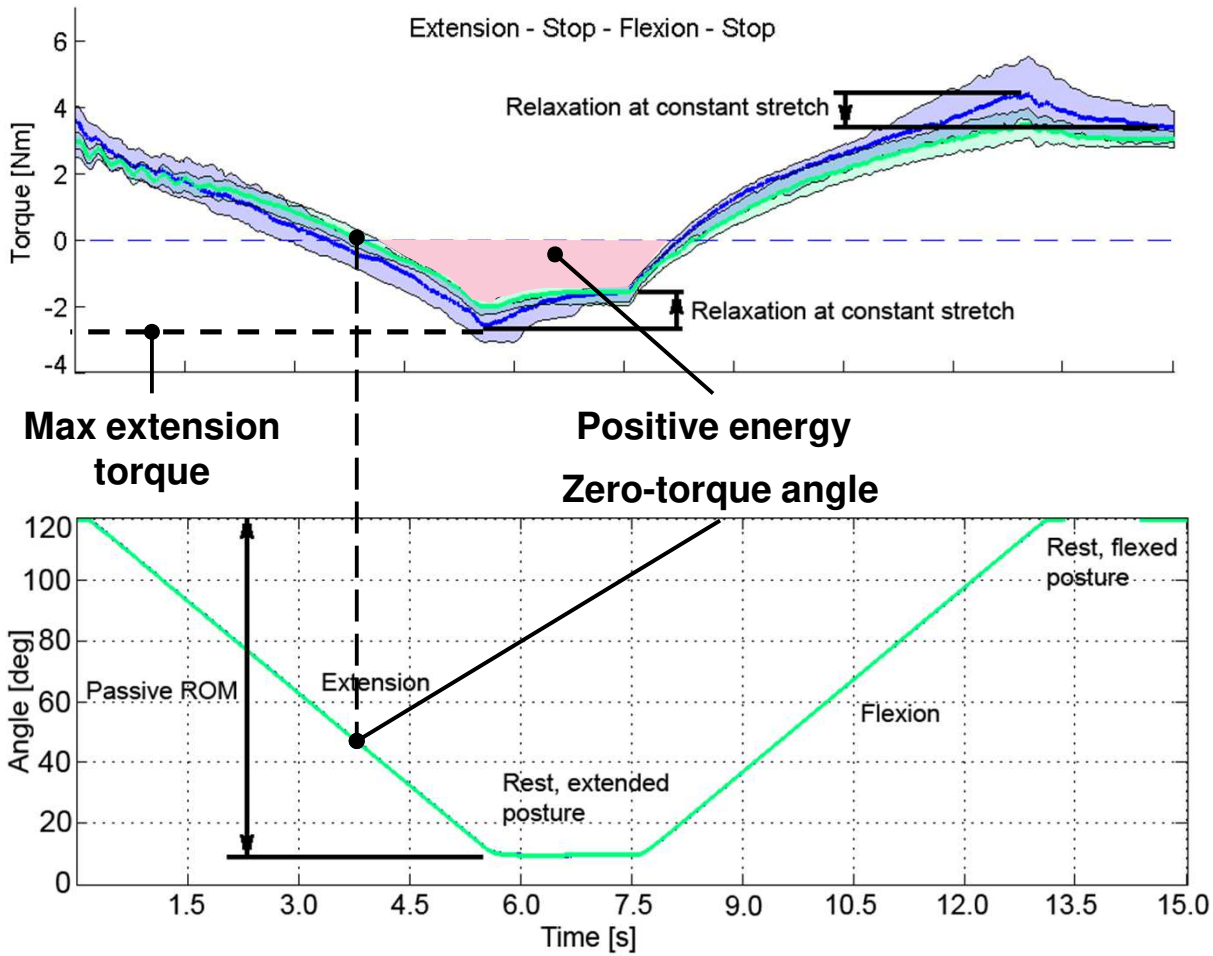
   Applied torque at maximum extension angle

2. Zero-torque angle

   Extension angle when the torque is null

3. Positive energy

   Energy injected by the device to fully extend the elbow starting from the zero-torque angle



Blu = day #1, Green = day #10

Posteraro et al., accepted to Italian Congress SIMFER 2015
Crea et al., Frontiers in Neuroscience, 2017, in press

Discussion

- In line with literature, in our populatio all the patients – but one – reporting spasticity in the pre-evaluation session *(MAS*>=1), reported the same after treatment and in the follow-up
- Kong and colleagues (2012) reported that 3 months after stroke 33% of patients present spasticity, 65% of which have a MAS>=1+. In our case only one participant showed MAS=1+ and no-one had a MAS>1+. Why?
  - Is the the intensive mobilization offered by the exoskeleton relevant?
  - The size of our sample is not significantly high -> we need a more large study with possibly a control group
- Our exoskeleton can work as an assessment tool
  - There is coherence between MAS and *MET/ZTA*
  - In some cases, in patients with no changes in MAS there were changes in the parameters MET/ZTA

Neuroexos shoulder module

ACCORDING TO THE CLINICAL ASSESSEMENT BUT, ABOVE ALL, ACCORDING TO THE ASSESSMENT PROVIDED BY ROBOTIC DEVICE ABLE TO AUTOMATICALLY MEASURE MAS AND ROM, PATIENTS CAN BE ADDRESS TOWARDS:

- **NEUROEXSOS SHOULDER OR ELBOW MODULE IF THEY ARE VERY SEVERELY IMPAIRED**
- **AN EXOSKELETON DEVICES WITH LOW FRICTION WHICH REQUIRE EXERCISE IN 3D SPACE (ALEX) WITH AND WITHOUT VIRTUAL REALITY FEEDBACK**
- **AN END EFFECTOR PLANAR DEVICE (MOTORE)**
- **A PASSIVE DEVICE WORKINF IN 3D SPACE FOR MILD IMPAIRED PATIENTS OR NOT NEUROLOGICALLY IMPAIRED (ULTRA)**

ALEX

MOTORE

MObile roboT for upper limb NeurOrtho REhabilitation

- It is a small haptic mobile device on wheels
- Autonomous robot
- Embedded actuation and control
- Large workspace
- Force feedback
- Omnidirectional movements
- It is a mobile robot, link-less, wireless
- Battery powered

ULTRA

CONCLUSION

Until now a lot of energies have been directed toward to develop

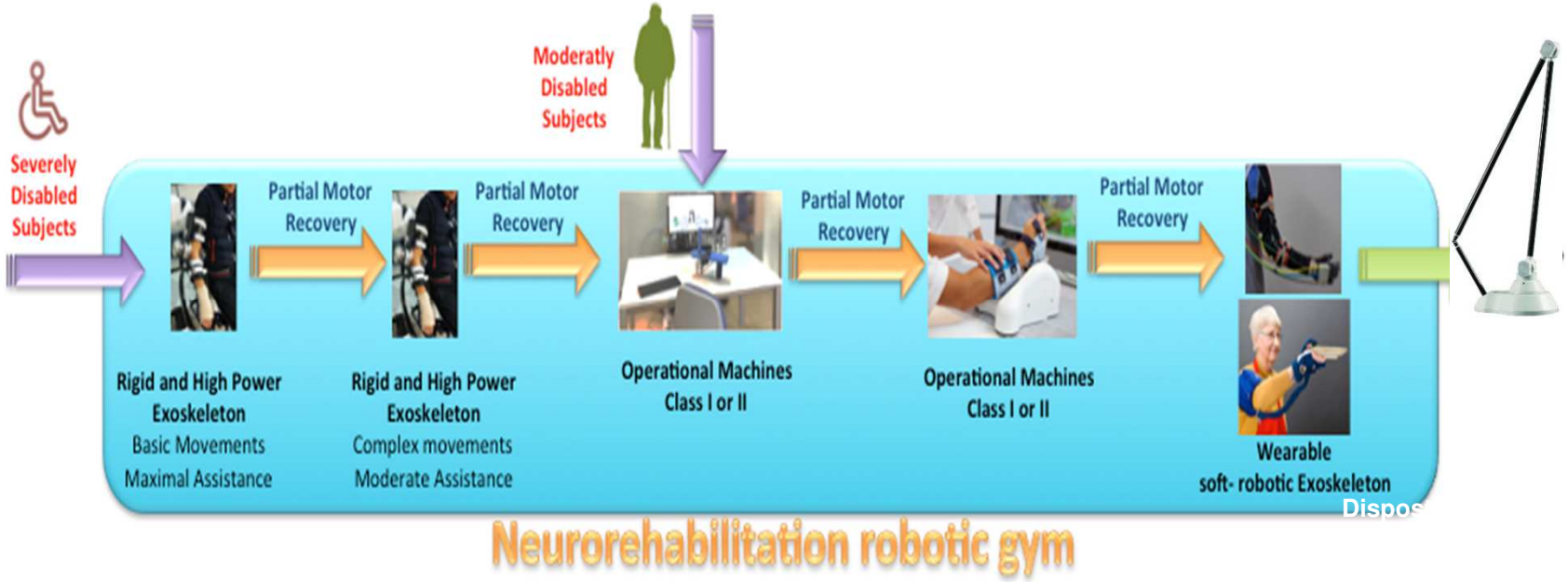
A MAGIC DEVICE

Only one device, very technologically advanced, able to tailor the exercise for all different kind of patients

RESULT

- **Very expensive device, not very friendly user**
- **The patients need to adapt to the device available.**

RONDA PROJECT



Many robotic devices able to provided specific exercise in order to really tailor the task to patient who, during the treatment, can change the device and not only exercises

In this perspective in RONDA Neurorehabilitation Robotic Gym, we have devices able to treat more severely impaired patients (NEEM; NESM) and at the same time to assess if they can be treated by other kind of device and to recognize when the patient can move from one device to another.

What about Recovering hand dexterity

Complexity of Hand Function

- A lot of degrees of freedom
- Wide representation in cerebral cortex and subcortical structures
- Very complex mechanism of control
- Very important role in ADL

Degrees of Freedom

- Three joints and four degrees of freedom for each finger resulting
- 20 degrees of freedom in total
- Activated by 29 muscles

Resulting in a very complex neurological control system

Wide representation in cerebral cortex and subcortical structures

At 3 months post-stroke,

- only 12% of stroke survivors report no difficulty with hand function
- 38% of survivors reported major difficulty with hand function
- Reduction of movement, increases in flexor tone, strength imbalances between antagonistic muscle groups result in a stereotypical flexed hand and wrist

FOR THIS REASON

- More than 30 robotic devices have been developed
- Only 6 (25%) are available on the market
- Many are end effector devices which are able to treat not severely impaired patients
- Other have only one degree of freedom

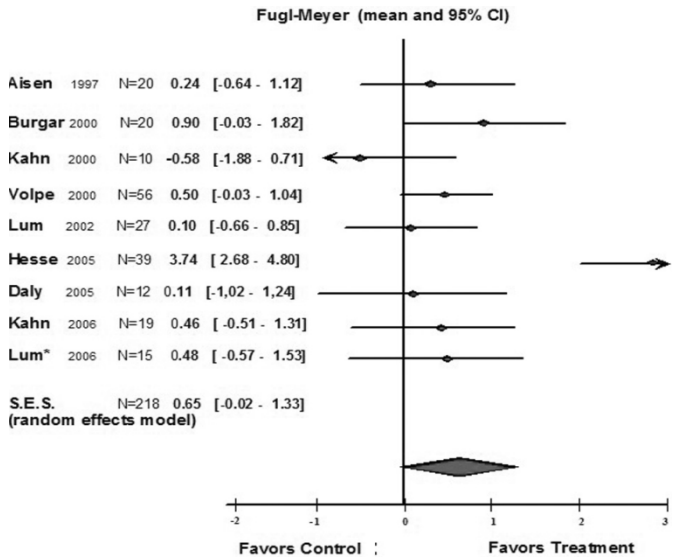
ANYWAY WE NEED ROBOTIC DEVICES FOR THE HAND

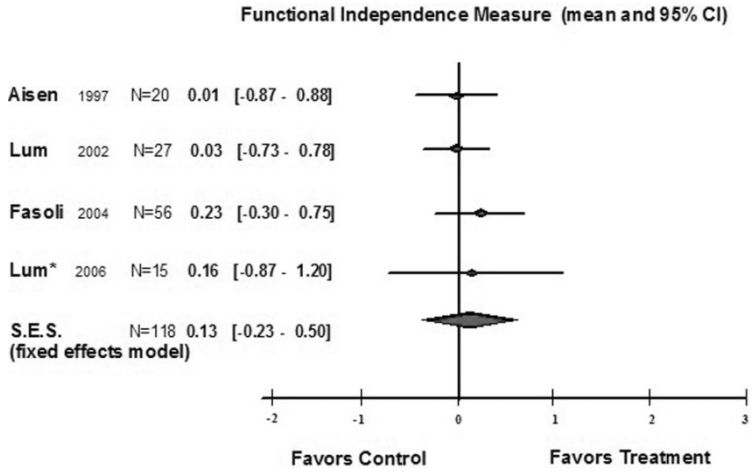
Literature

Neurorehabilitation and Neural Repair (2008): Effects of Robot-Assisted Therapy on Upper Limb Recovery After Stroke: A Systematic Review

Gert Kwakkel, PhD, Boudewijn J. Kollen, PhD, and Hermano I. Krebs, PhD

Conclusion: In summary, the present systematic review confirms the potential for robotic assisted devices to elicit improvements in proximal upper limb function. **<u>However, improvements in terms of ADLs could not be substantiated</u>**





SOME EXPERIENCES

HAND OF HOPE

An EMG-driven Exoskeleton Hand Robotic

END-EFFECTOR

By measuring his/her surface electromyography (EMG) signals from the impaired hand muscles, this robotic device detects the stroke person's intention and assists in hand opening or hand closing.

MAS Score > 3 represent a contraindication at use.

HAND OF HOPE

An EMG-driven Exoskeleton Hand Robotic

1) Detects the intention to move:

   Hand of Hope detects the user's intention, which is emitted from the brain to the forearm in the form of voluntary EMG signals.

2) Processes the motion signal:

   The device processes and delivers the EMG signals to the hand brace.

3) Assists the movement:

   The hand brace assists the user by enabling the intended hand motion.

4) Gathers positive feedback:

   The user re-learns hand functions through repetition and Feedback.

5) Interactive games:

   Real-time interactive games actively involve the user and enhance the training results.

HandCARE: A Cable Actuated Rehabilitation System to Train Hand Function After Stroke

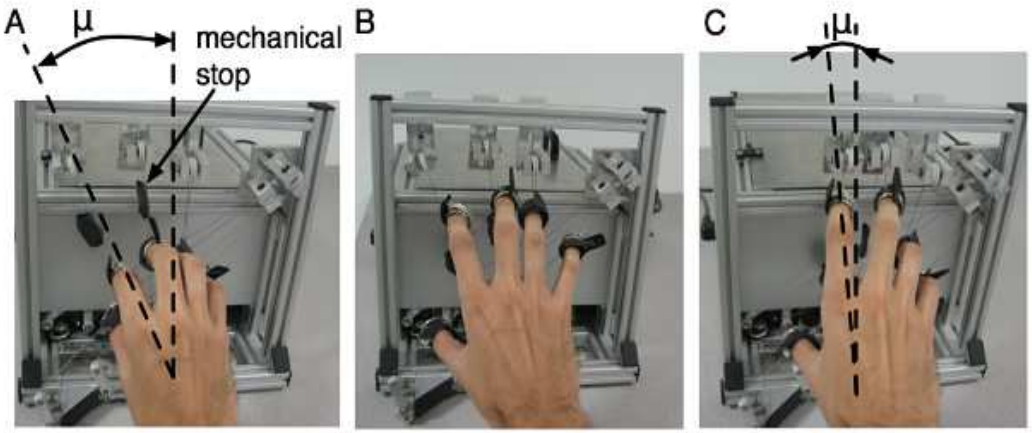
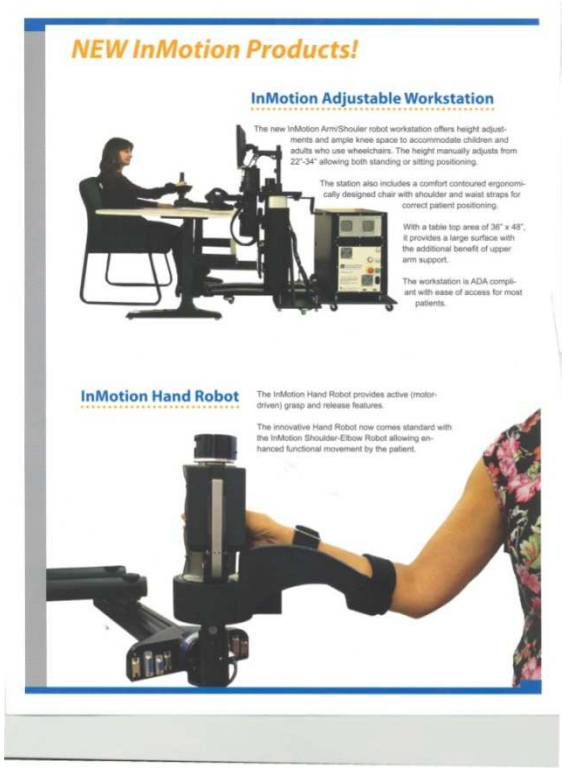


Fig. 4. Hand in closed (A) and open position (B). The fixtures can be adjusted to change the orientation μ of finger trajectories (C). Different movements can be trained, e.g., opening/closing with five fingers (A), (B) or with tripod thumb-index-middle fingers (C).

It was developed about ten years ago. No clinical trial has been performed



NEW InMotion Products!

InMotion Adjustable Workstation

The new InMotion Arm/Shoulder robot workstation offers height adjustments and ample knee space to accommodate children and adults who use wheelchairs. The height manually adjusts from 22"-34" allowing both standing or sitting positioning.

The station also includes a comfort contoured ergonomically designed chair with shoulder and waist straps for correct patient positioning.

With a table top area of 36" x 48", it provides a large surface with the additional benefit of upper arm support.

The workstation is ADA compliant with ease of access for most patients.

InMotion Hand Robot

The InMotion Hand Robot provides active (motor-driven) grasp and release features.

The innovative Hand Robot now comes standard with the InMotion Shoulder-Elbow Robot allowing enhanced functional movement by the patient.

Motion Hand

- An add on module to be used with the InMotion ARM™ Robot (whole arm system).
- It provides assist-as-needed grasp and release training with flexible positioning. It may be used in neutral (vertical) or pronation mode for patients with limited range due to developmental or tone impairments.
- Limitation is due to only one DOF

EMG-controlled Exoskeleton Mulas et al 2005

Thumb – FE,
other fingers
together – FE

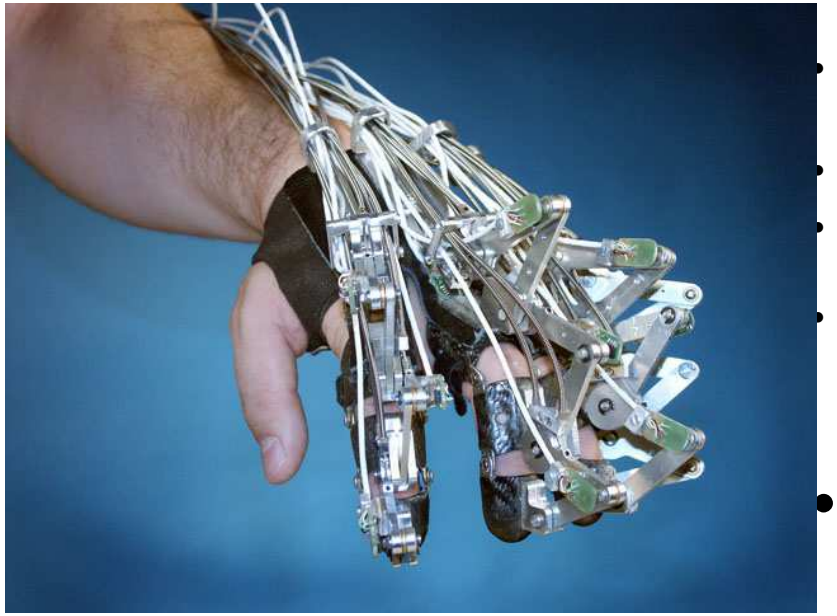
EMG signals detected were from Flexor Digitorum Superficialis and Flexor Pollicis Longus.

The system is able to move passively the finger and after they start with EMG when muscle strength became enougth

This control strategy is useful only in a more advanced phase of the therapy, when the patient is able to produce a significant amount of muscle activity

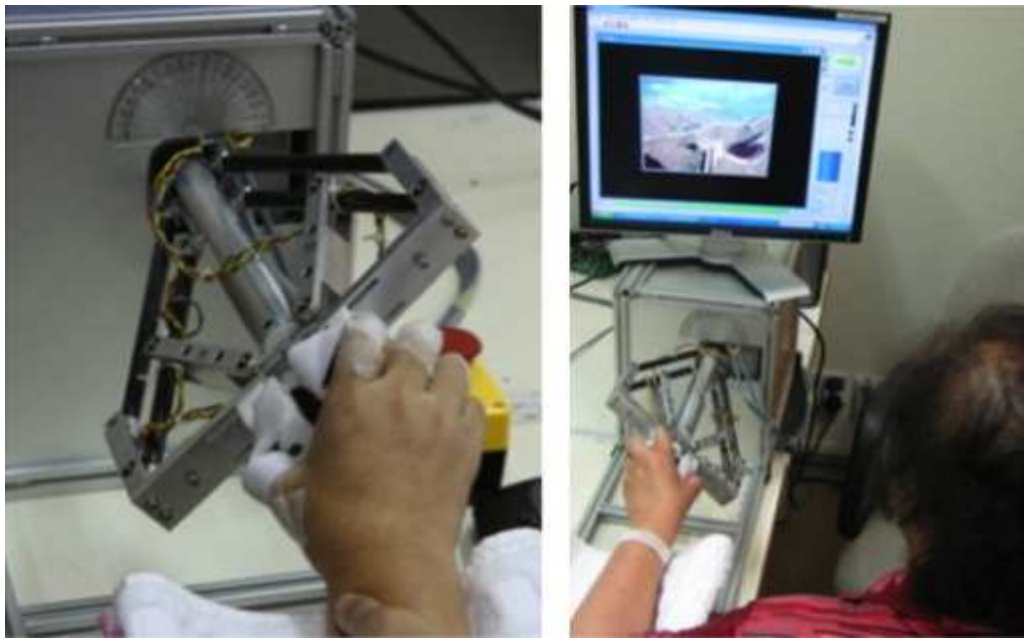
Powered Hand Exoskeleton

Technische Universität Berlin



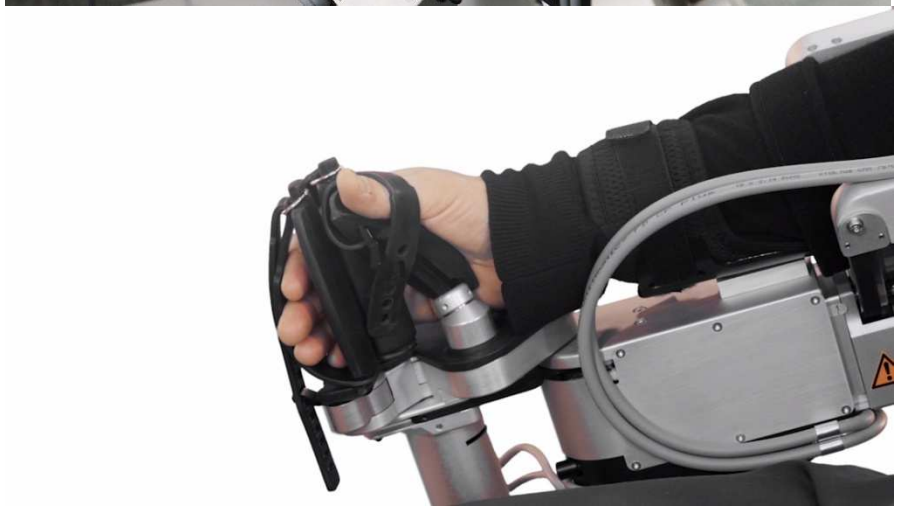
- The actuation is performed by electric motors which transmit forces to the joint through Bowden cables
- 20 active degrees of freedom (four for each finger)
- Joint angle sensors (Hall sensor and encoders)
- Force sensors at finger tips
- Up to 16 EMG Sensors
- Very complex. It was developed in 2009 but It remained at prototype level

- HapticKnob Grasping in coordination with pronation/supination of the forearm.



ARMEO POWER + MANOVO

Hocoma



- It has been specifically designed for arm and hand therapy in an early stage of rehabilitation.
- Assist-As-Needed Movement Guidance
- It works in extensive 3D workspace
- The Hand Function Module enables severely impaired patients to relearn hand opening and closing. Enables patients to train reaching and grasping with assist-as-needed support from shoulders to fingers.
- Only one DOF

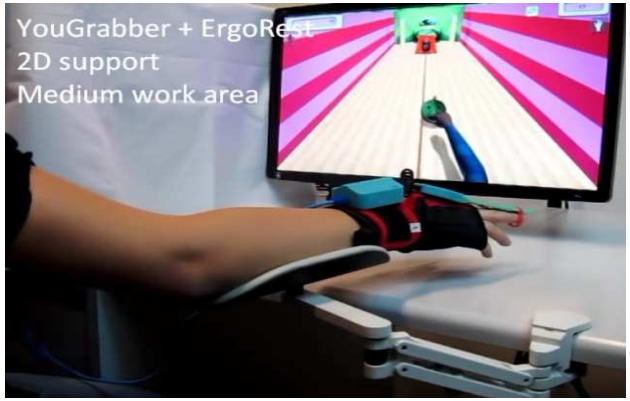
HEnRiE

It is a grasping device is attached to the HapticMaster end-effector, a 3D projection screen is positioned in front ofthe subject, a thin Kevlar wire connects the elbow cuff with the arm gravitycompensation motor positioned above the subject.

The Hand module has one DOF

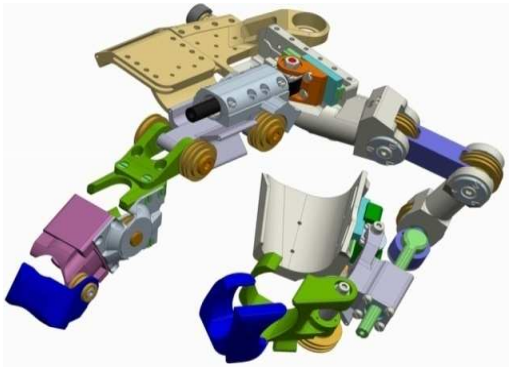
YouGrabber

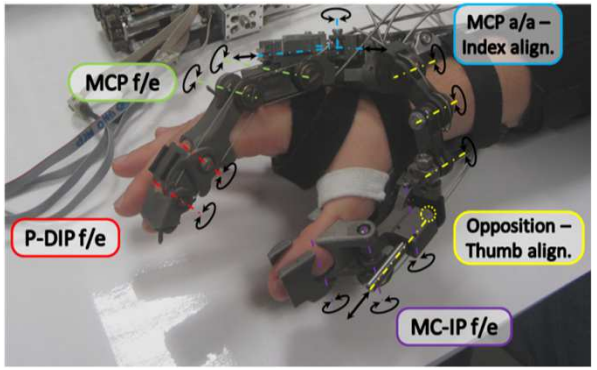
- It is an upper limb rehabilitation solution from YouRehab, is an innovative system that offers exercises for fingers and arms through a series of fun interactive games
- The system uses a PC, an infrared tracking camera, and patented adjustable data gloves. The interactive training applications are designed for different arm and finger movements and use virtual games.
- It is not actuated



A PROTOTYPE
HandExoskeleton (HX) -

The HandeXos is a robotic device designed to assist the hand in performing an array of different grasping tasks.





HX Device:

- Enveloping two fingers(index-thumb)
  - Low weight and complexity;
  - Able to perform a wide array of grasping motions thanks to the thumb opposition cinematics.
- Endowed with passive Degrees of Freedom (DoF) to increase adaptability.

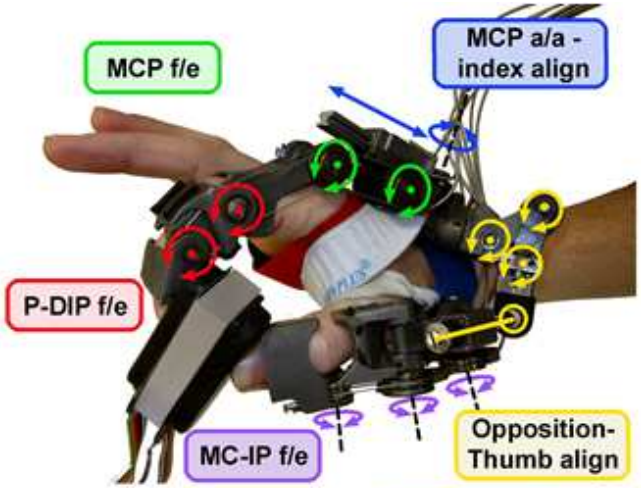
ISTITUTO DI BIOROBOTICA
Scuola Superiore Sant'Anna

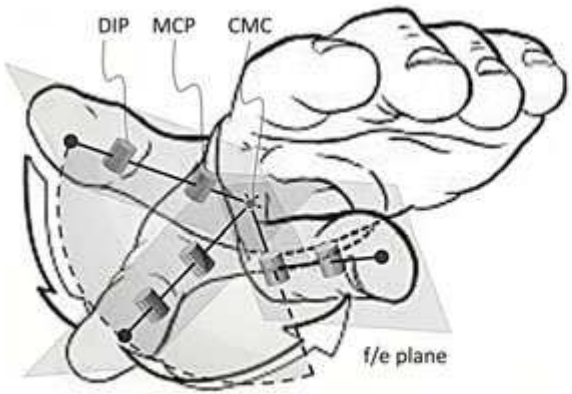
Cempini et al., IEEE TMECH, 2015
Cortese et al., IEEE TMECH, 2015

Developer: *Wearable Robotics Lab led by* ***Prof. Nicola Vitiello*** *The Biorobotics Institute Scuola Superiore Sant'Anna*

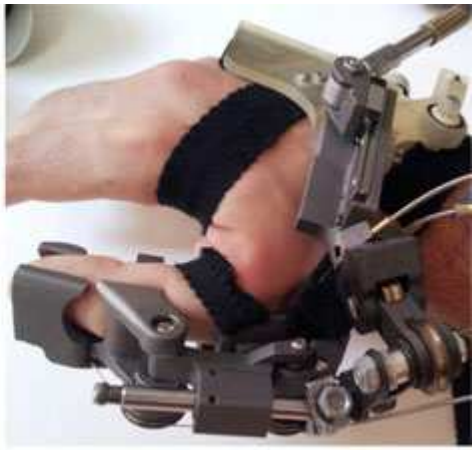
Kinematic Structure

- 420 grams;
- 13 Total DoFs – 7 Actuated DoFs;
- 5 Actuators (under-actuation);
- 10 transmission cables;
- Ranges of Motion (RoM) comparable to the human's;
- Able to implement the thumb opposition movement.





(a)



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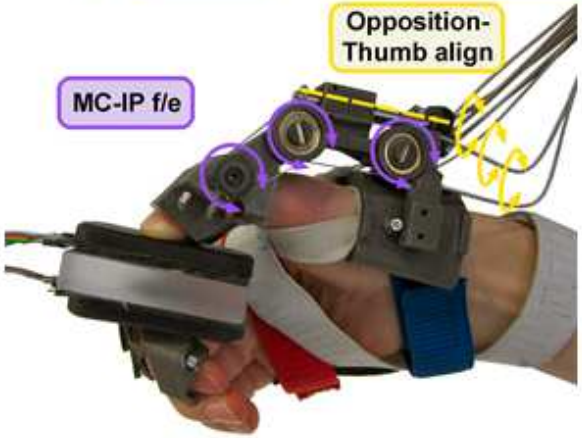

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THANK YOU FOR

YOUR ATTENTION