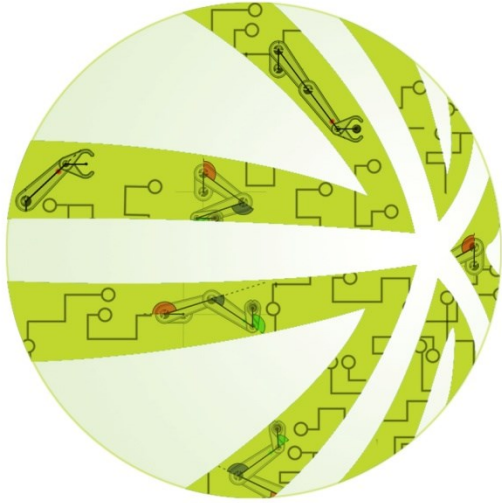




IISART

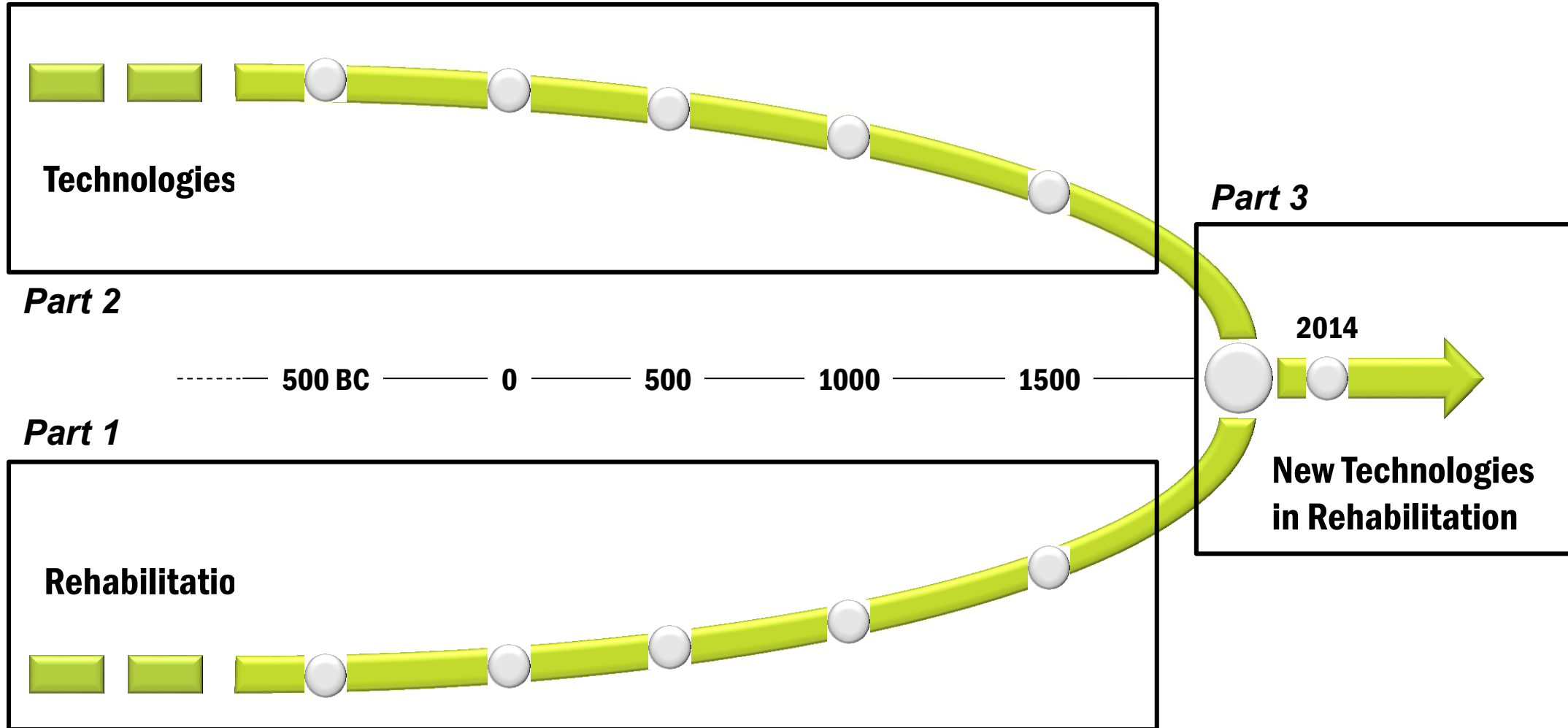
INTERNATIONAL INDUSTRY SOCIETY IN
ADVANCED REHABILITATION TECHNOLOGY

History of New Technologies in Rehabilitation

Audience



Overview



1. History of Rehabilitation

2. History of Technologies

3. New Technologies in Rehabilitation

3.1 Robot-Assisted Therapy

3.2 Non-Actuator Devices

3.3 Functional Electrical Stimulation

3.4 Sensor Technology

3.5 Virtual Reality

3.6 Brain Stimulation

1

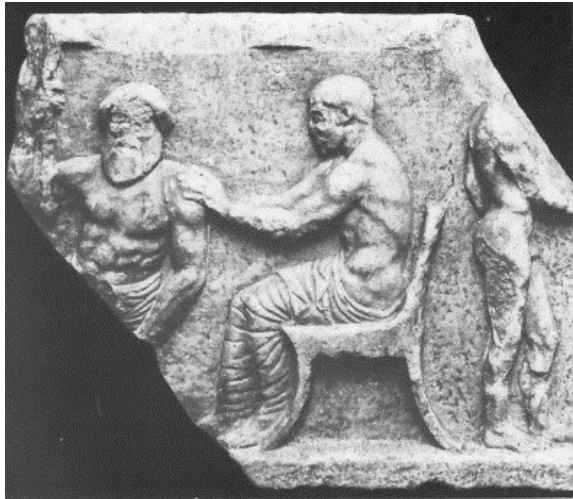
HISTORY OF REHABILITATION

Rehabilitation ...

"...is the (re)integration of an individual with a disability into society. This can be done either by enhancing existing capabilities or by providing alternative means..."

Robinson 1993

~2000 years old



shoulder massage (relief)

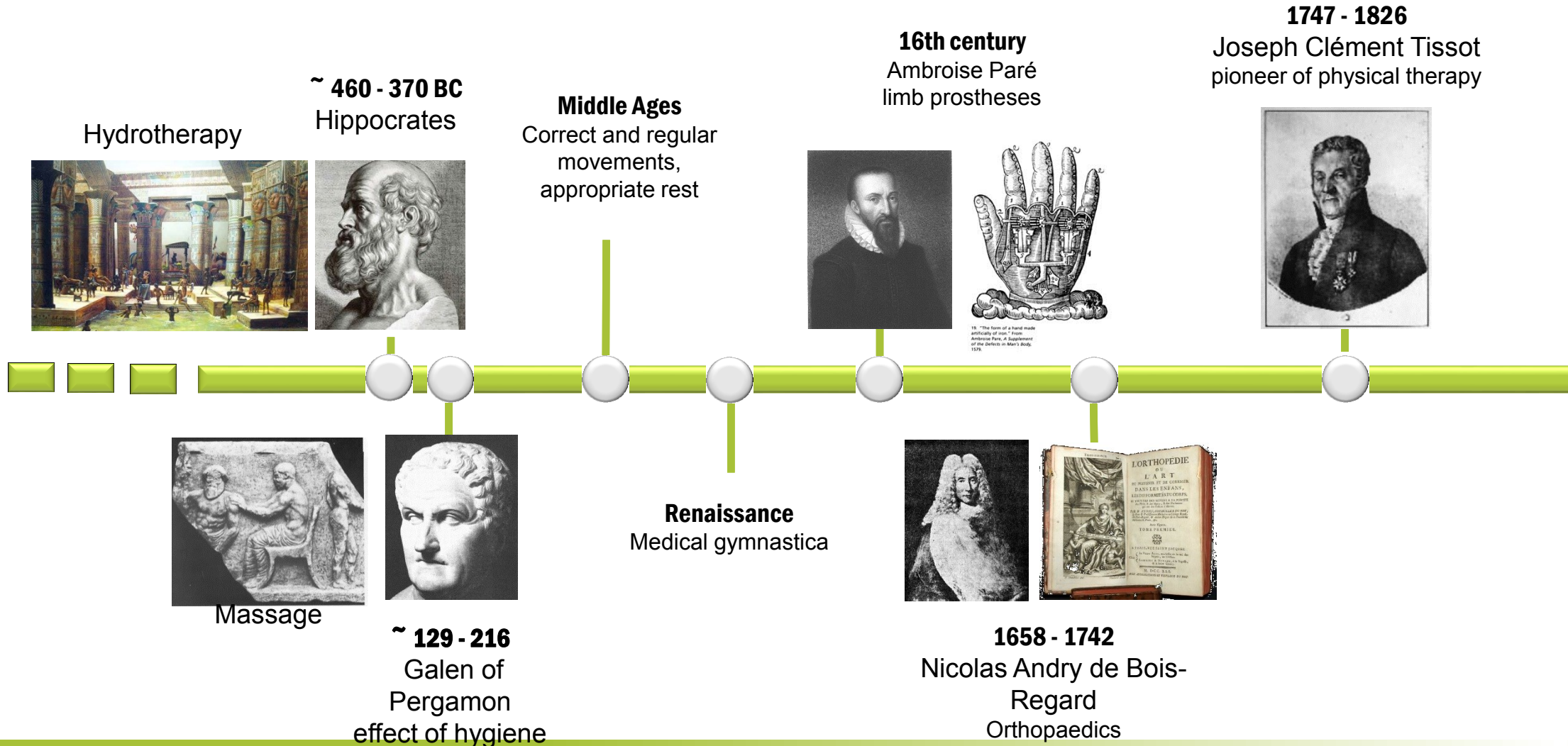


present



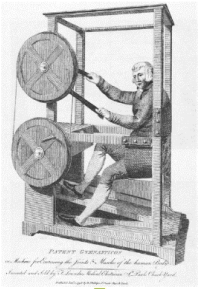
practice of daily tasks

History of Rehabilitation



History of Rehabilitation

1796
Gymnasticon
machine for
exercising the joints



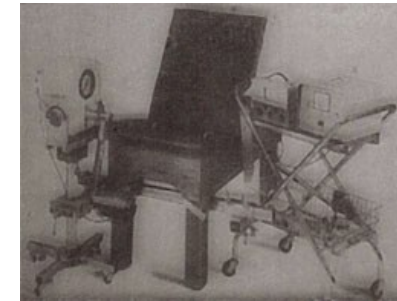
1894
Chartered Society
of Physiotherapy

World War I
Vacuum tube
peripheral stimulation

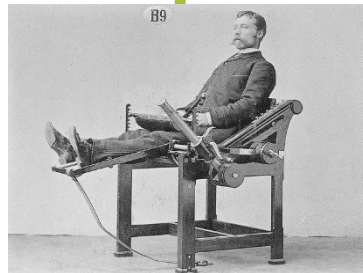


1943
Karel & Berta Bobath
bobath concept

1967
Cybex I
first isokinetics machine



1813
Pehr Henrik Ling
physical therapy



1835 - 1920
Gustav Zander
mechanotherapy



World War II
Howard A. Rusk
first rehabilitation units

1948
Thomas DeLorme
progressive resistance training

Compensation

- Walking aids



Crutches



Wheelchairs

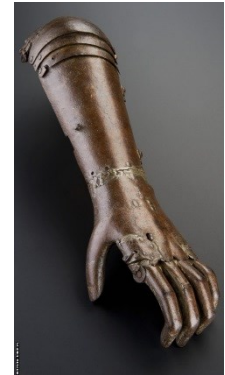


Walkers

- Prostheses



Prosthetic toe

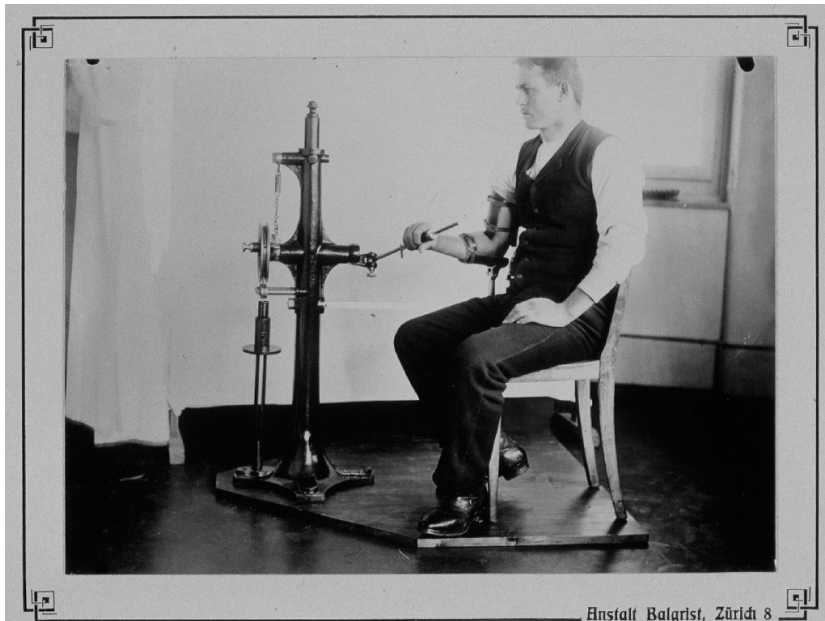


Iron Arm

Restoration

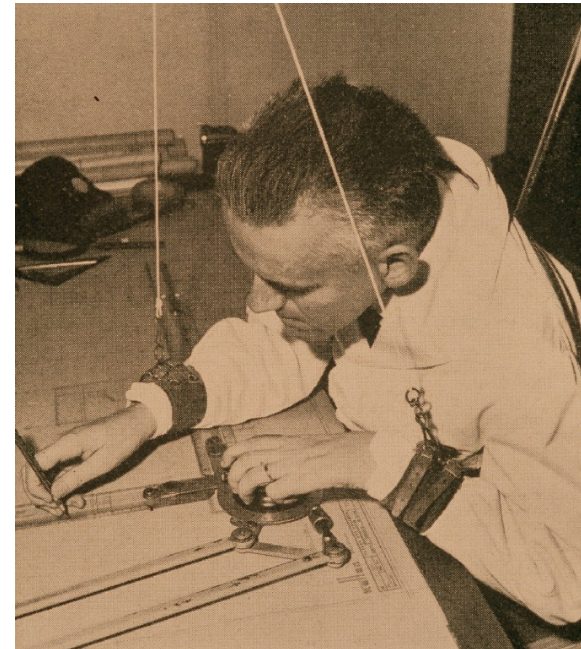
- Physiotherapy

Increase mobility and function



- Occupational therapy

Increase independence



Manual Arm Therapy

Target patient group

- Hemiplegic/tetraplegic patients
- Patients with cerebral palsy, traumatic brain injury and other neurological lesions
- Patients with orthopedic lesions or joint pain

Therapy goals

- Train activities of daily living (ADL)
- Reduce contractures by stretching joints
- Avoid secondary complications

➔ Improve arm function, patient well being and patient independence



Conventional Gait Therapy

For the therapist

- Not standardized (repeatable)
- Physically exhausting
- Ergonomically inconvenient (manual handling risk)

For the patient

- Limited in time
- Multiple therapists needed
- Gait pattern not optimal



2

HISTORY OF TECHNOLOGY

Technology ...

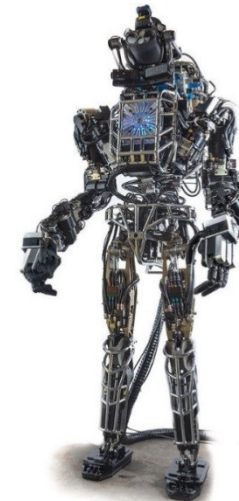
"...is the collection of tools, including machinery, modifications, arrangements and procedures used by humans."

Wikipedia

~800'000 BC

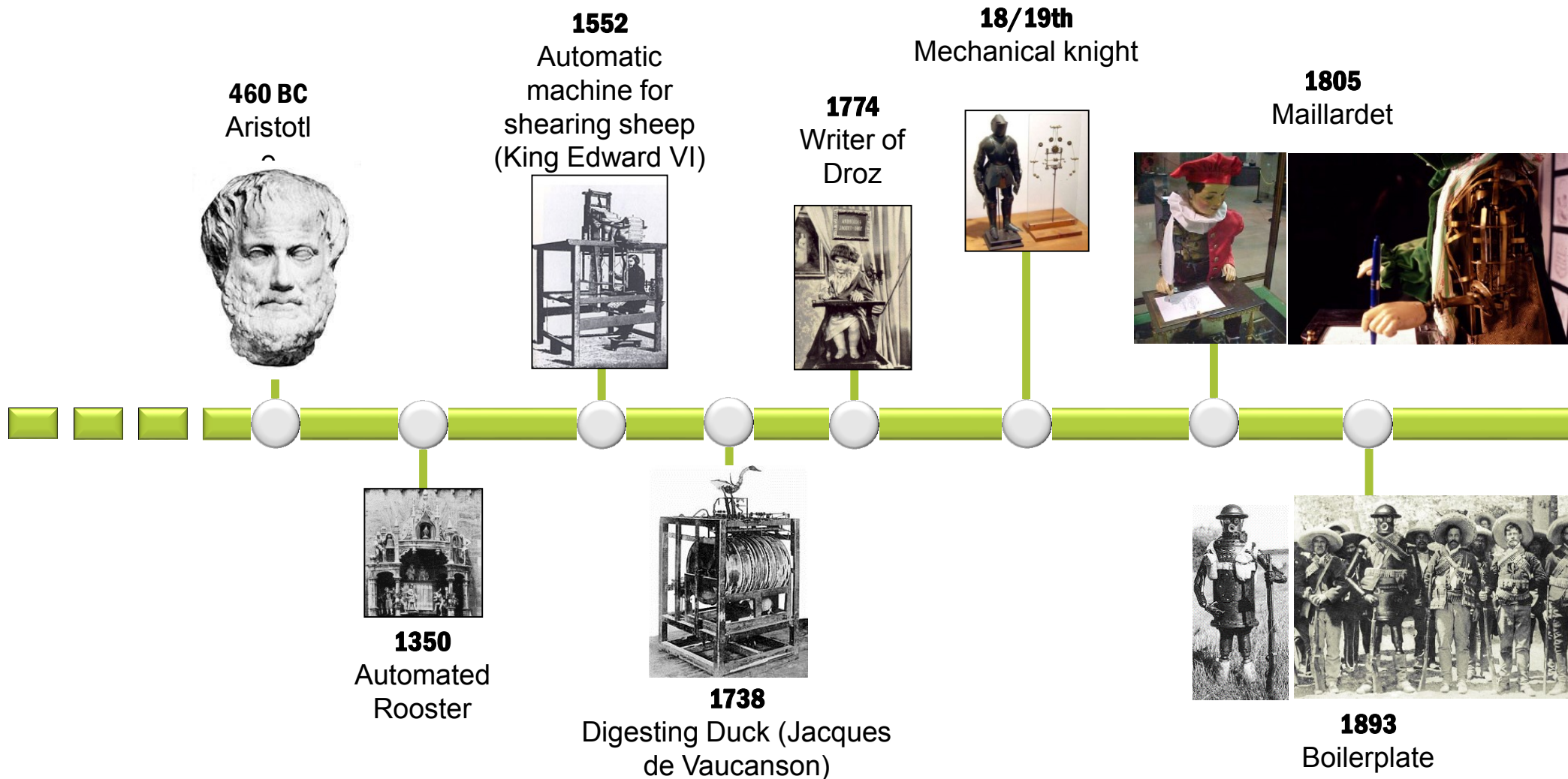


2013



Atlas, bipedal humanoid robot

History of Technology

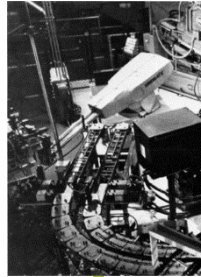


History of Technology

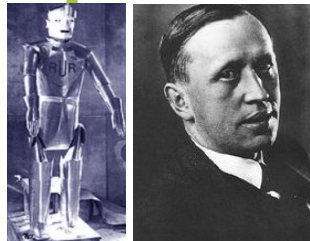
1940
Westinghouse's
Electro



1954
UNIMATE



1979
Selective Compliant
Articulated Robot
Arm (SCARA)



1920
R.U.R. (Karel
Capek)

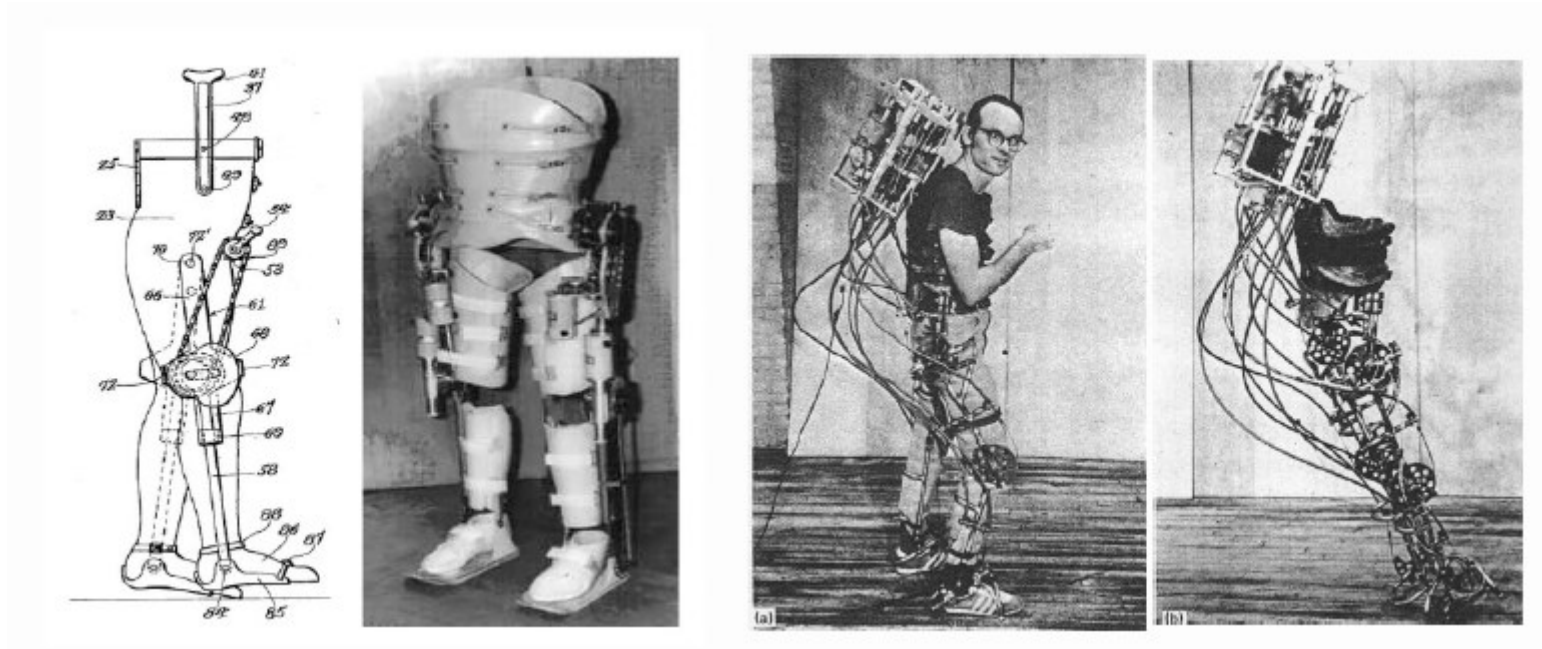


1942
«Runaround»
(Isaac Asimov)



1973
WABOT-1

Early Active Orthoses



**Cobb's «wind up»
orthosis**
(Cobb, 1935)

**Pupin Institute
«complete»
exoskeleton**
(Vukobratovic, 1990)

**Wisconsin exoskeleton
orthosis**
(Seireg & Grundmann, 1981)

Powered Exoskeletons



«Yagn's running aid»
(Yagn, 1890)



«General Electric's
Hardiman»
(Fick & Mackinson, 1971)



«Bleex»
(Kazerooni & Steger, 2006)



«HAL», Hybrid Assistive Limb
(Tsukuba University, JP)

3

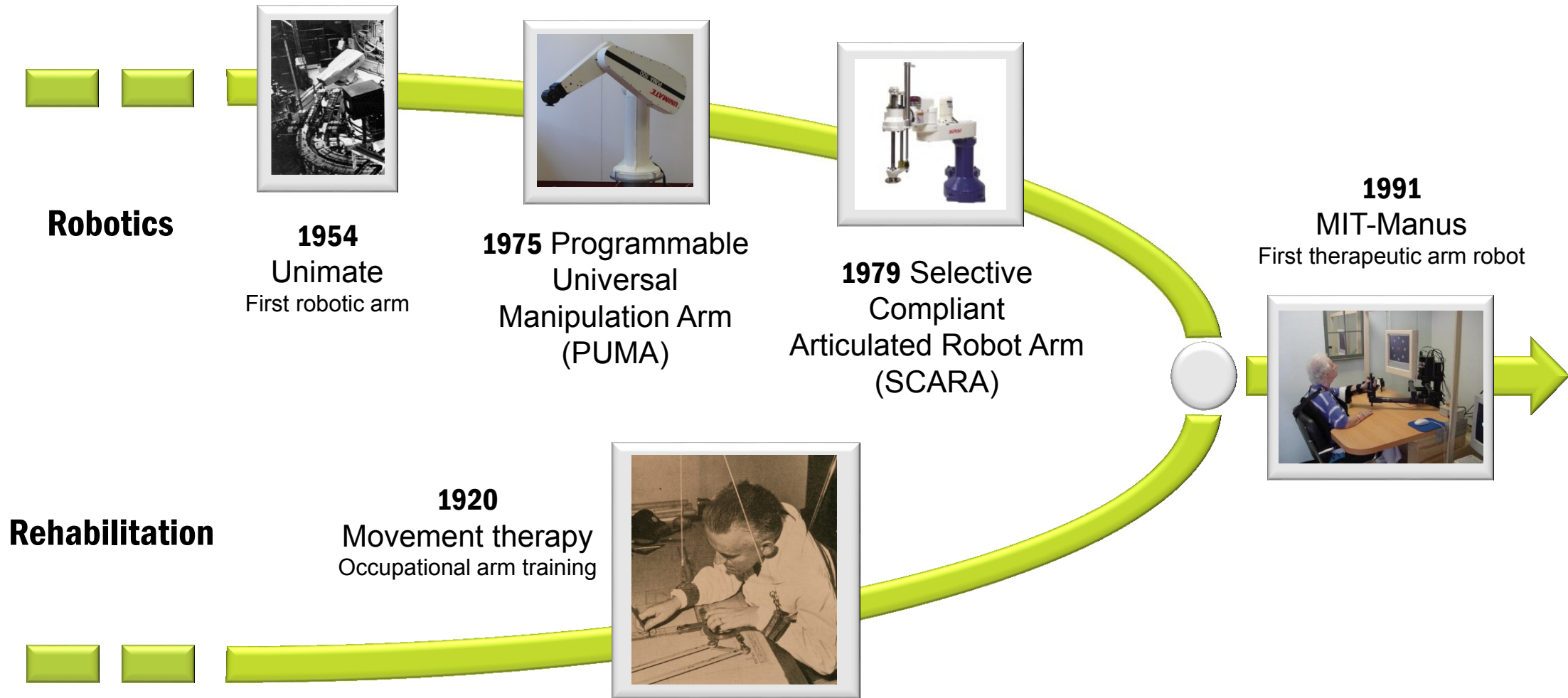
NEW TECHNOLOGIES IN REHABILITATION

3.1

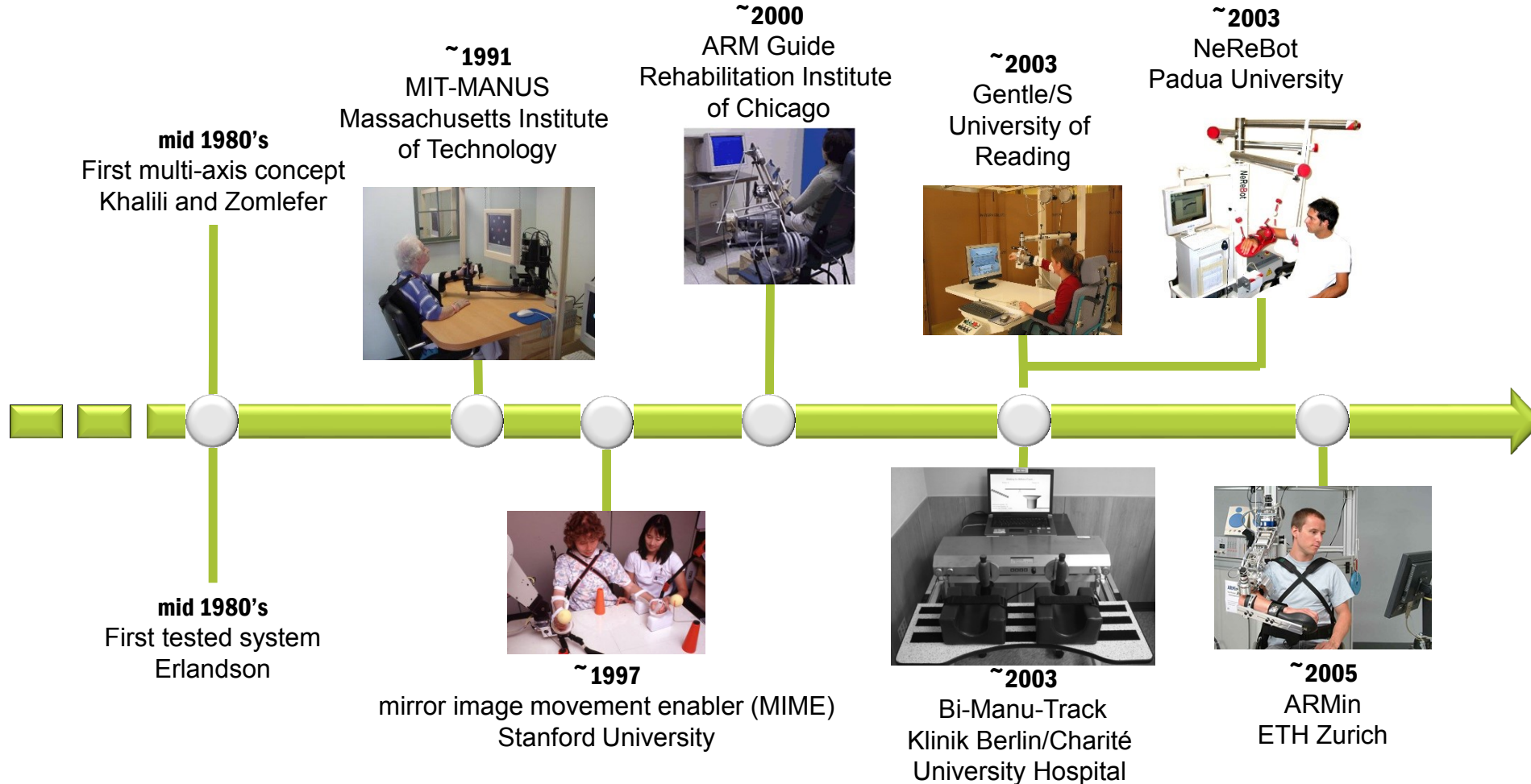
HISTORY OF ROBOTIC REHABILITATION

Upper Limbs

Beginning of Robotic Rehabilitation



Upper Limbs Therapeutic Robots



MIT-Manus (~1991)

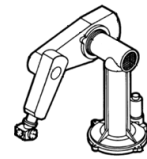


MIT-Manus (Krebs et al. 2000)

Characteristics



Newman Laboratory for Biomechanics and Human Rehabilitation
Massachusetts Institute of Technology (MIT)



2-DoF end-effector type robot
based on a selective compliance assembly robot arm (SCARA)



Assists shoulder and elbow movements in the horizontal plane



First upper limb therapeutic robotic device Move, guide or perturb a patient's limb
Measure position, velocity and forces applied



InMotion ARM

MIME (~1997)

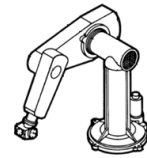


Mirror Image Movement Enabler (Lum et al. 1999)

Characteristics



Veterans Affairs Palo Alto Rehabilitation Research and Development (RR&D) Center



6-DoF end-effector type robot, 3-D space based on Puma 560 industrial robot manipulator



For training unilateral or bilateral shoulder and elbow movements



Passive mode, active-assisted mode, active-resisted mode, bimanual mode (movement mirroring to impaired limb)



ARC-MIME

ARM Guide (~2000)

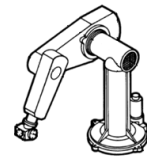


Assisted Rehabilitation and Measurement Guide
(Reinkensmeyer et al. 2000)

Characteristics



Rehabilitation Institute of Chicago, University of California
Irvine



3-DoF (1 active DoF)



Arm reaching in 3-dimensions

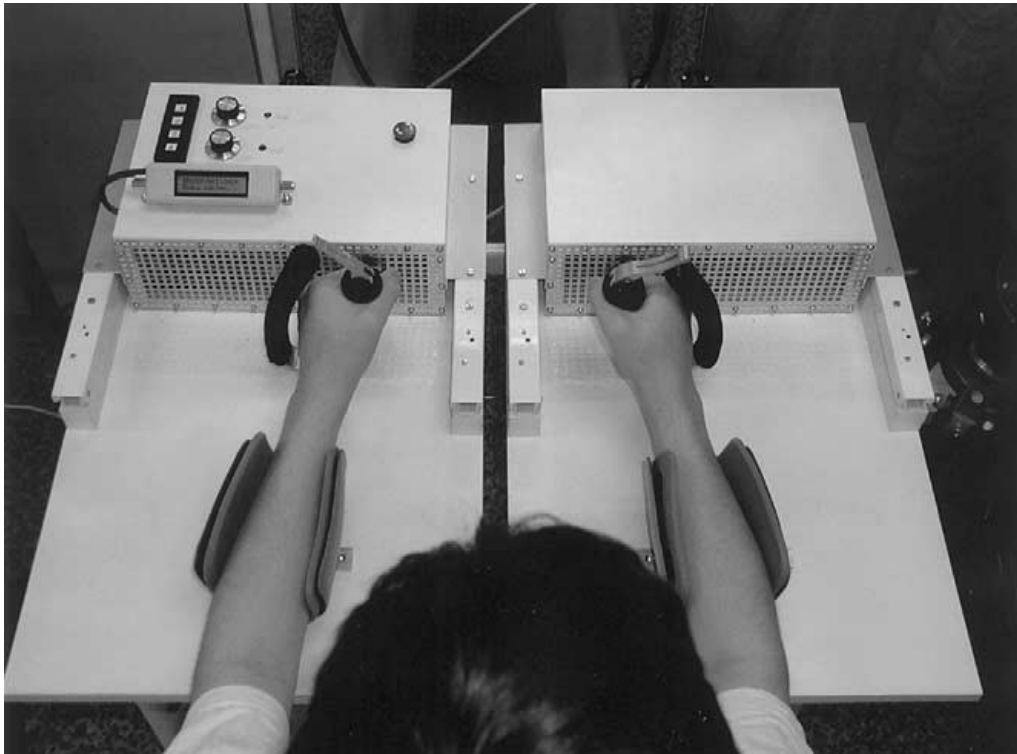


Assessments and therapy, exploring the effects of active
assist therapy
Real time visual feedback of the arm



ARC-MIME

Bi-Manu-Track (~ 2003)

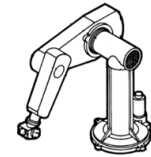


Bi-Manu-Track (Hesse et al. 2003)

Characteristics



Klinik Berlin/Charité University Hospital (Berlin)



1-DoF end-effector type robot



Distal arm movements,
bilateral elbow pro- and supination and wrist flexion and
extension



Provides bimanual practice, passive and active exercises
against an adjustable resistance, no feedback



Bi-Manu-Track

GENTLE/S (~2003)

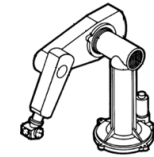


Gentle/S (Loureiro et al. 2003)

Characteristics



Human Robot Interface Laboratory, Department of Cybernetics and School of Systems Engineering, University of Reading



6-DoF robot (3-DoF manipulator (Haptic-Master) + 3 DoF gimbal)



Elbow pro- and supination and wrist flexion and extension



Uses haptics and VR technology



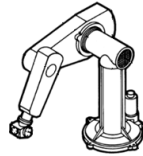
HapticMaster (component)

NeReBot (~2003)

Characteristics



Robotics Laboratory of the Department of Innovation in Mechanics and Management, University of Padua



3-DoF end-effector type, wire-based robot



For shoulder and elbow



Principle of hand-over-hand therapy
Robot learn movements of therapists and repeat those later on with patients.
Visual and auditory feedback



NEuro REhabilitation roBOT (Fanin et al. 2003)

ARMin (~2005)

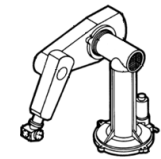


ARMin (Nef et al. 2007)

Characteristics



Sensory-motor-systems Lab, swiss federal institute of technology (ETH) Zurich



1st version: 4 DoF end-effector-based
2nd version: 6 DoF exoskeleton



For shoulder and elbow



Adjustable to arm length
3 training modes: mobilization, game training and ADL training.



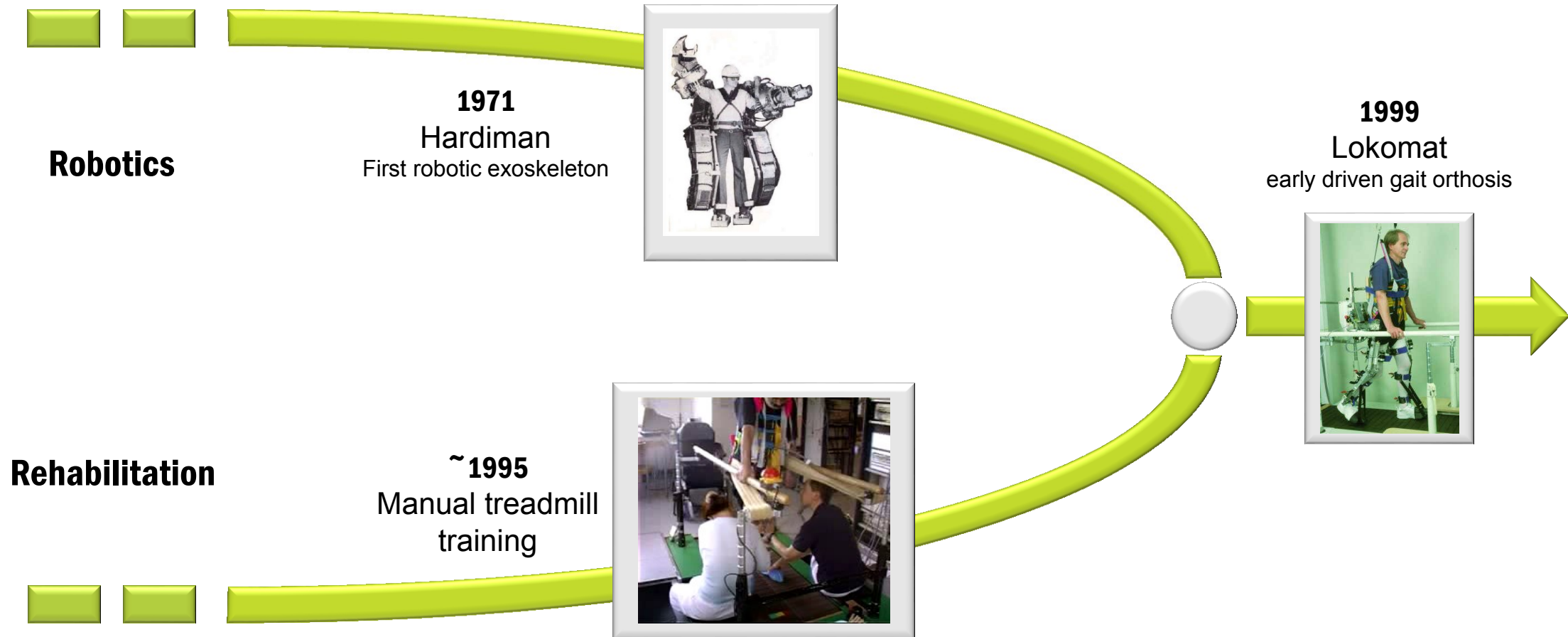
ArmeoPower

3.1

HISTORY OF ROBOTIC REHABILITATION

Lower Limbs

Beginning of Robotic Rehabilitation



Lower Limbs Therapeutic Robots



~1999
Lokomat
(Hocoma)



~1999
Gait Trainer GT-1
(Reha Stim)



~2002
Reo/AutoAmbulator
(Health South, Motorika)



~2008
Lopes
(van Asseldonk et al.)

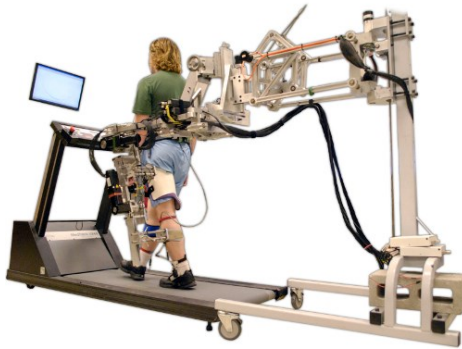


~2008
Haptic Walker
(Hussein et al.)

Lower Limbs Therapeutic Robots



2009
PowerKnee
Tibion PK 100
(Horst)



~2009
ALEX
(University of Delaware)



~2010
Anklebot
(Khanna)



~2010
G-EO-System
(Health South, Motorika)

Lokomat (~1999)

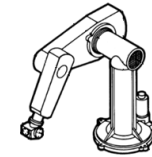


Lokomat (Colombo et al. 2000)

Characteristics



Balgrist University Hospital,
Hocoma Volketswil



4-DoF driven gait orthosis (exoskeleton) combined with
treadmill and body-weight-support

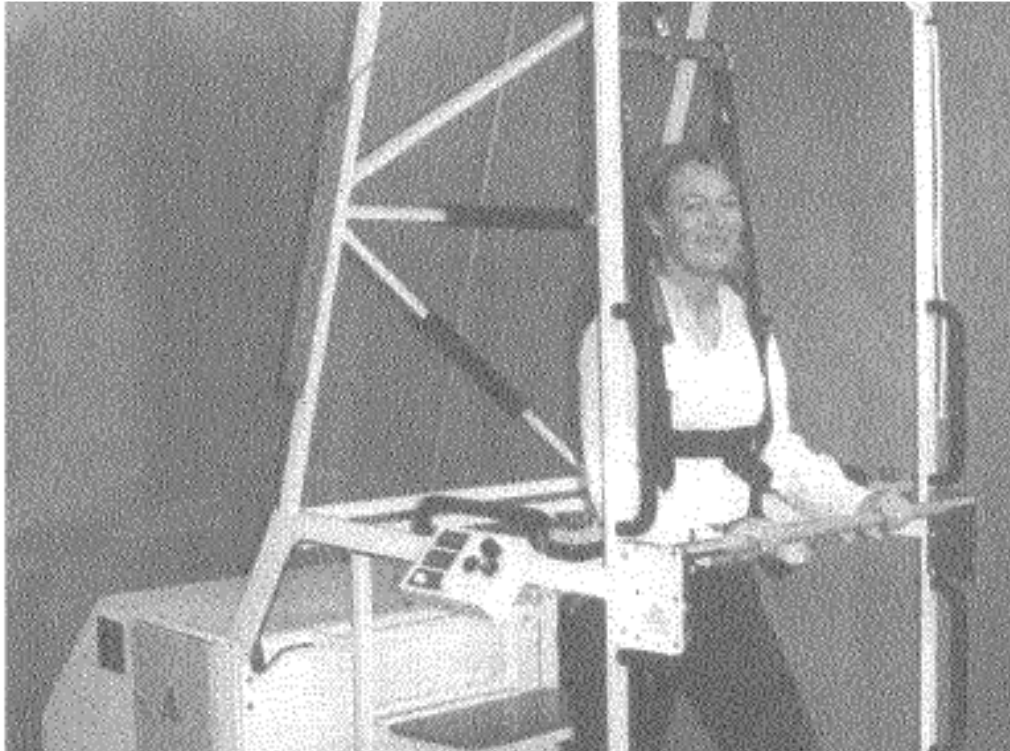


First driven gait orthosis with a treadmill
Adjustable force, body weight support and speed



LokomatPro

Gait Trainer (~ 1999)

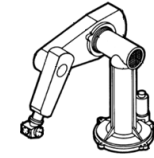


Gait Trainer (Hesse et al. 2000)

Characteristics



Klinik Berlin/Charité University Hospital (Berlin)



Based on a doubled crank and rocker gear system, end-effector type



Simulation of stance and swing
Control of the vertical and horizontal movements of the center of mass



Gait Trainer GT I

Reo/AutoAmbulator (~2002)

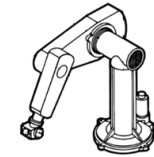


ReoAmbulator

Characteristics



Cooperation with HealthSouth network of rehabilitation hospitals



Robot arms move with 4-DoF (bilateral hip and knee flexion/extension), exoskeleton



Assistance only in sagittal plane

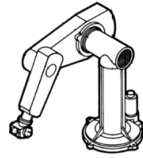


Reo/AutoAmbulator

Characteristics



Department of Biomedical Engineering, University of Twente,
Enschede



8-DoF lightweight exoskeleton



Translational movements of the pelvis are included along with
extension-flexion and abduction-adduction



Lower-extremity Powered ExoSkeleton

Haptic Walker

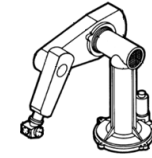


Haptic Walker

Characteristics



Fraunhofer Institute IPK, Klinik Berlin/Charité University Hospital (Berlin)



End-effector type (footplates)

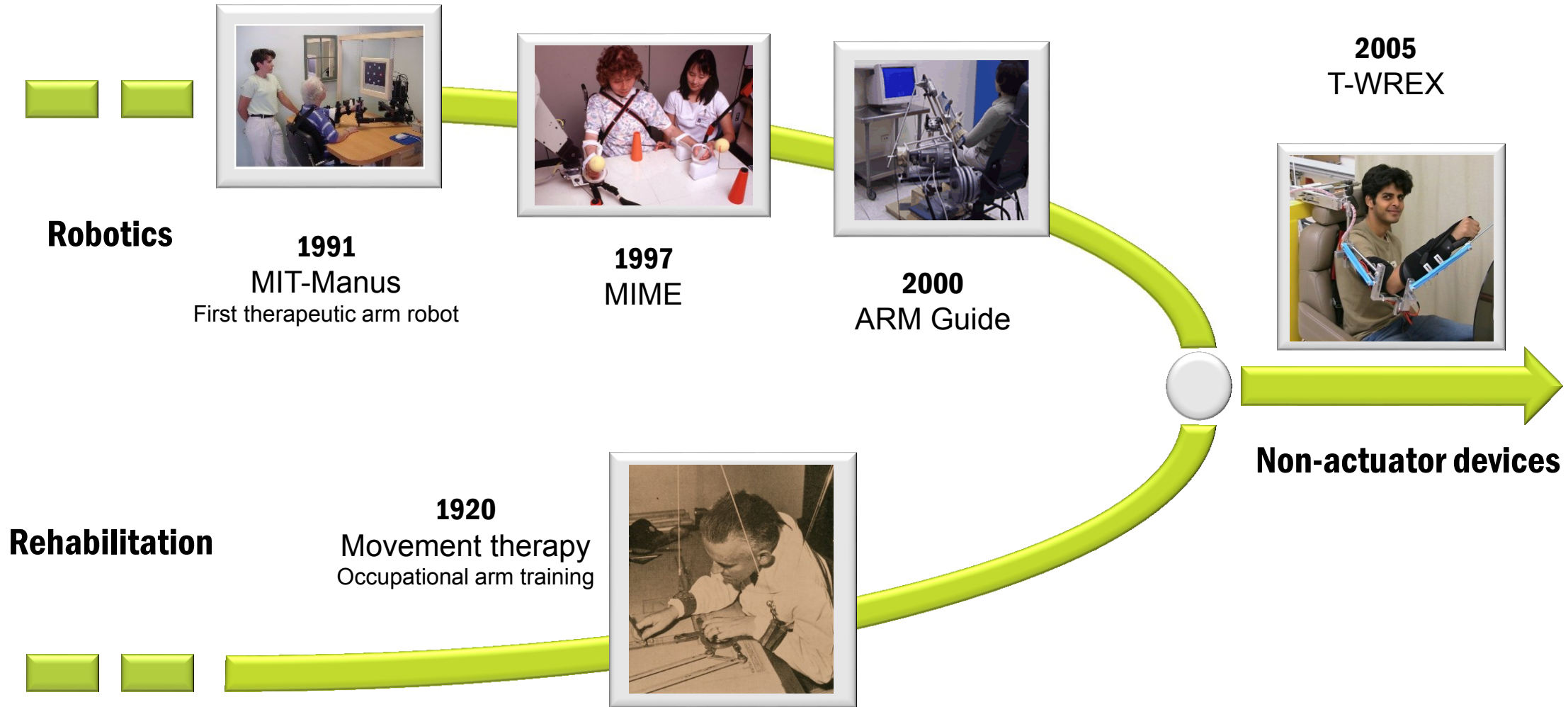


Permanent foot-machine contact, training not restricted to walking on even ground

3.2

NON-ACTUATOR DEVICES

Beginning of Non-Actuator Devices



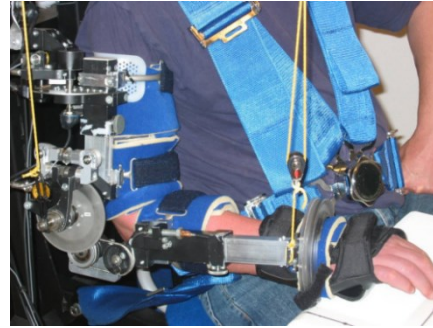
History of Non-Actuator Devices

~ 2005



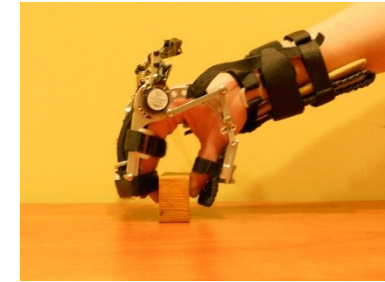
T-WREX

~ 2007



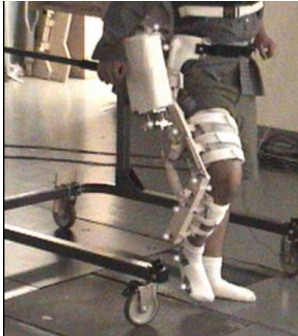
Dampace

~ 2011



HandSOME

Gravity balanced orthosis



~ 2003

Freebal



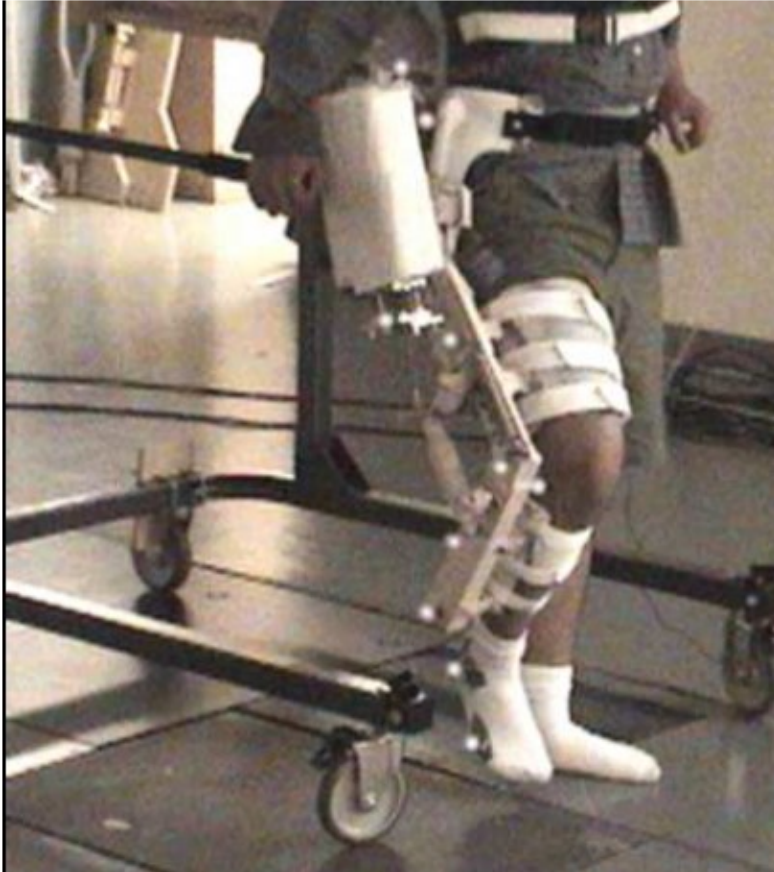
~ 2007

ZeroG passive



~ 2010

Gravity balanced orthosis (~2003)

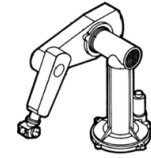


GBO (Agrawal et al. 2007)

Characteristics



Robotics And Rehabilitation Lab,
University of Delaware



Gravity balancing un-motorized orthosis (exoskeleton)

i

Full or partial gravity balance over the leg's range of motion
Tunable to the geometry and inertia of individual subjects

Training WREX (~2005)

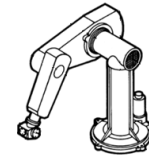


Therapy/Training-Wilmington Robotic Exoskeleton
(Sanchez et al. 2004)

Characteristics



Department of Mechanical and Aerospace Engineering,
University of California, Irvine



5 DoF backdrivable exoskeleton with arm weight
counterbalancing using elastic bands



Adaption of the WREX device for use in movement training of
stroke patients
Equipped with position sensors



ArmeoSpring

Freebal (~2007)

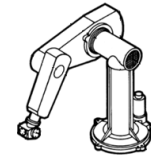


Freebal (Stienen et al. 2007)

Characteristics



Department Biomechanical Engineering,
University of Twente, Enschede



Sling systems with ideal spring mechanisms

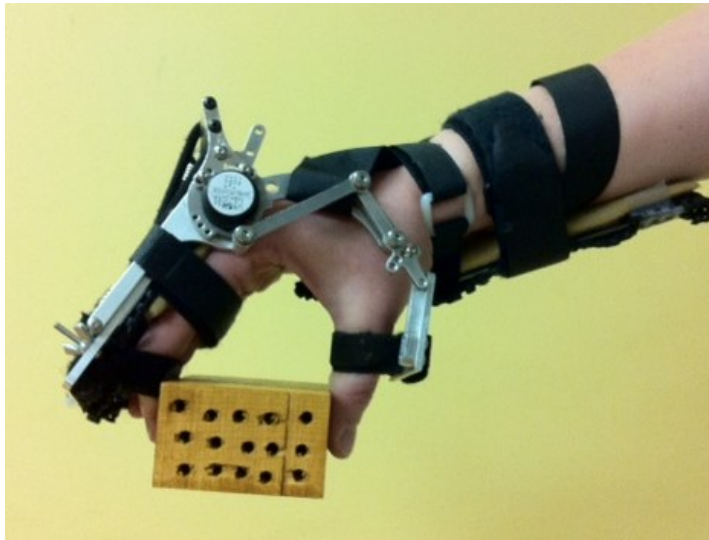


Independent control of the compensation of the lower and
upper arm
Low movement impedance



ArmeoBoom

HandSOME (~2011)

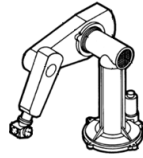


HandSOME (Brokaw et al. 2011)

Characteristics



MedStar National Rehabilitation Hospital
and Biomedical Engineering at The Catholic
University of America, Washington DC



Spring-powered assist of pinch-pad grasp



Synchronized movement of fingers and
thumb with adjustable assistance for hand
opening



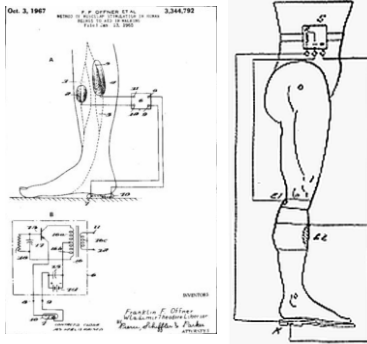
ManovoSpring

3.3

HISTORY OF FUNCTIONAL ELECTRICAL STIMULATION

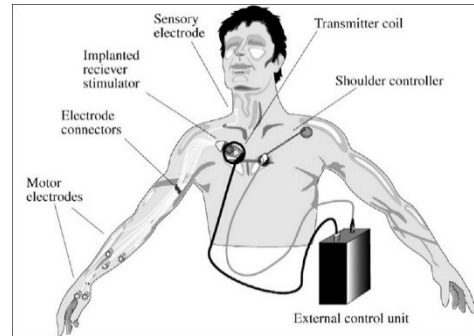
History of FES

~1961



Electronic personal stimulator
Wladimir Theodore Liberson

~1986



Freehand System

~1993



Handmaster NMS-1

Parastep I



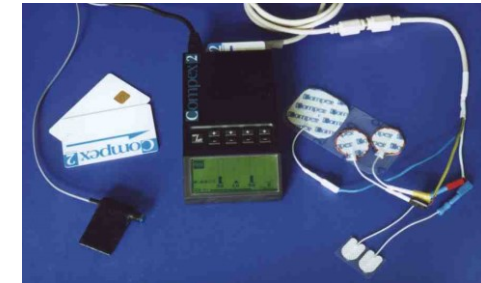
~1982

Bionic Glove



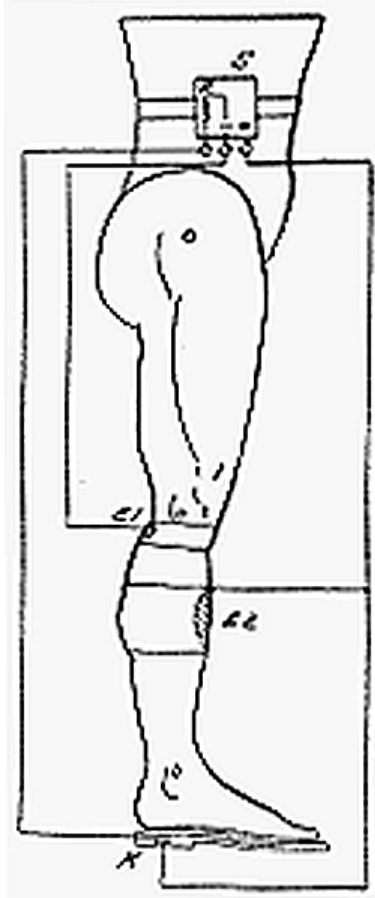
~1989

Complex Motion



~1999

Drop Foot Stimulator (~ 1961)

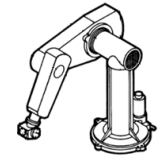


Liberson et al. 1961

Characteristics



Liberson et al. 1961



Electrically stimulates the common peroneal nerve
Uses foot-switch to synchronize applied electrical stimulation to swing phase of gait

i

First functional electrical stimulator (FES)
Developed to prevent foot-drop in hemiplegic patients

Parastep I (~ 1982)

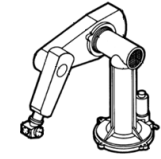


Parastep I

Characteristics



Sigmedics Inc.



Noninvasive, microcomputer controlled functional neuromuscular stimulation (FNS) system

i

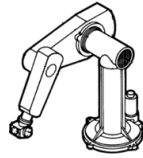
Enables independent, unbraced ambulation (i.e., standing and walking) by people with a spinal cord injury

Freehand System (~ 1986)

Characteristics



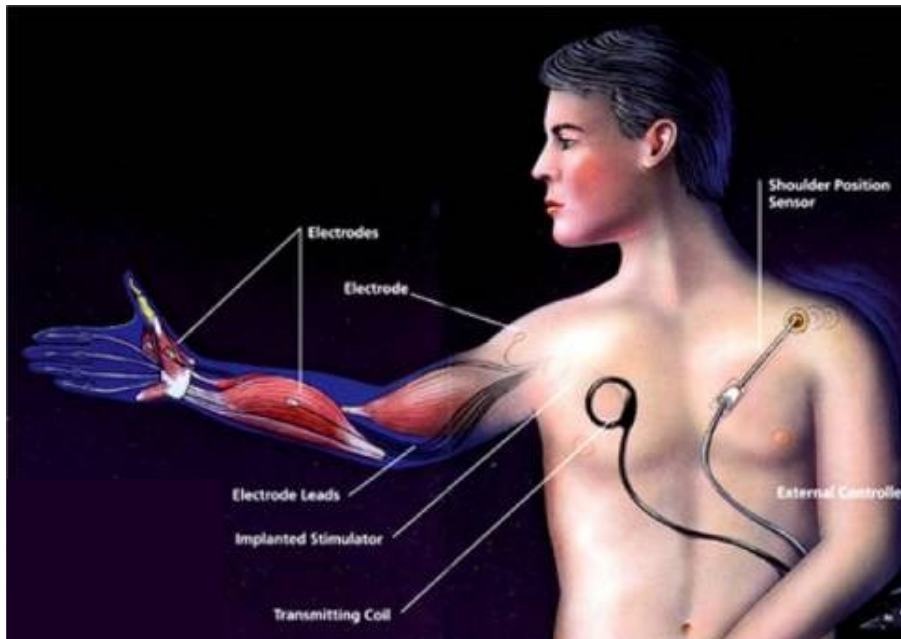
NeuroControl Cleveland, USA



Surgically implanted receiver/stimulator unit and electrodes with an external controller and power supply/microprocessor

i

Neuroprosthesis intended to restore hand function in C5 and C6 level tetraplegics
Stimulation of eight different muscles in order to produce a useful grip and key pinch



Freehand System

Bionic Glove (~ 1989)

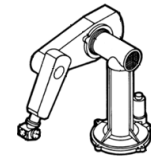


Bionic Glove

Characteristics



Prochazka et al., University of Alberta



Three channels of electrical stimulation to stimulate finger flexors, extensors and thumb flexors.
Control signal comes from a wrist position Transducer mounted in the garment

i

Enhance grasp in subjects that have voluntary control over the wrist
Stimulates finger flexors and extensors
Enhances strength of grasp

Handmaster NMS-1 (~ 1993)

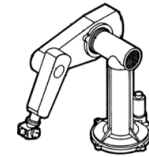


Handmaster NMS-1 (Nathan 1993)

Characteristics



Bioness (formerly Neuromuscular Electrical Stimulation Systems Ltd.)



Lightweight, ergonomical arm-hand orthosis with integrated FES and separate, wireless control unit.



Reaching, grasping, opening and closing the hand



Ness H200

Complex Motion (~1999)

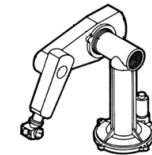


Complex Motion

Characteristics



University Hospital, Zurich
Rehabilitation Engineering Group ETH Zurich
Complex SA, Switzerland



Portable electrical stimulator with 4 stimulation channels and surface stimulation electrodes

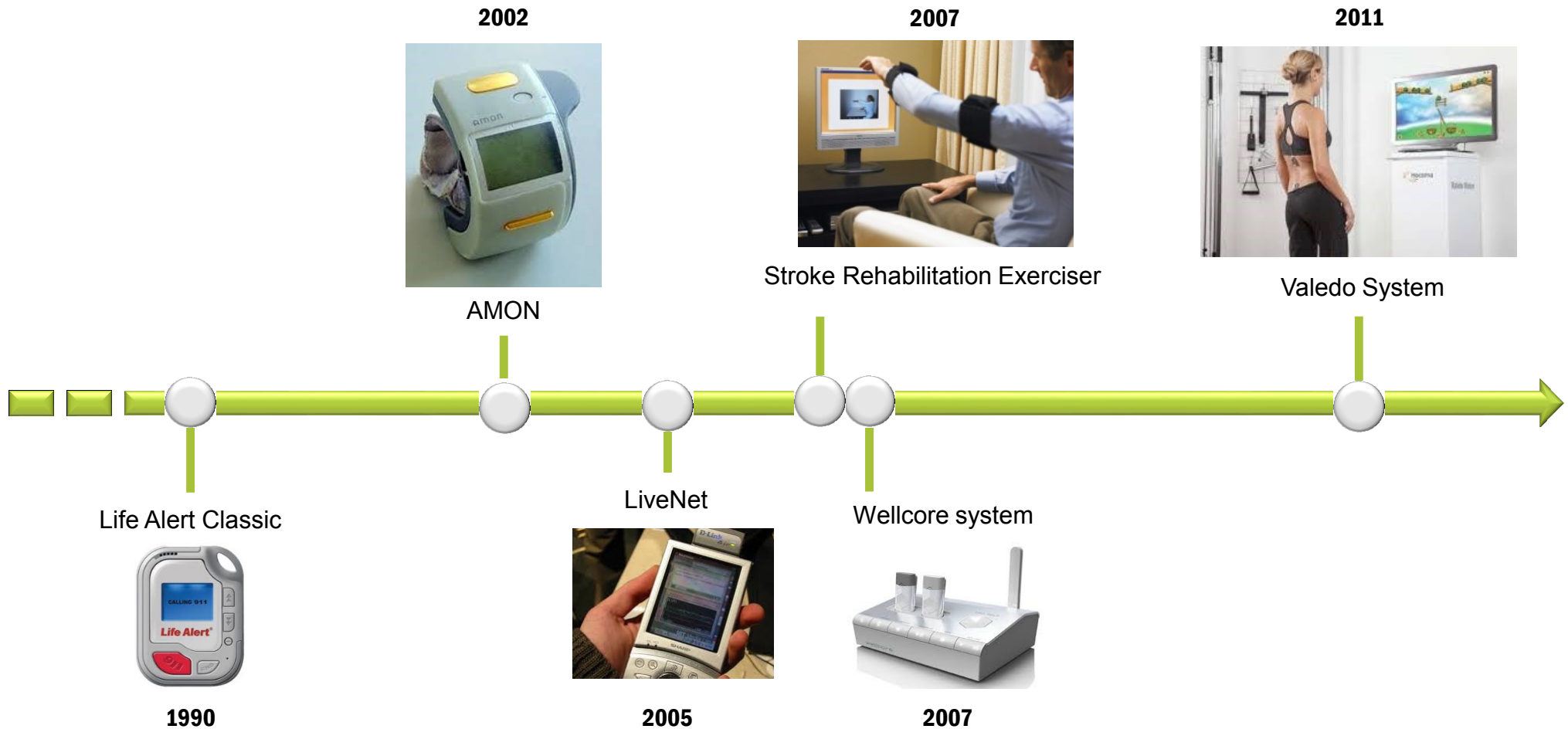
i

Able to generate arbitrary stimulation sequences which can also be controlled by external sensors
Multiple stimulators can be combined to increase number of stimulation channels

3.4

HISTORY OF SENSOR TECHNOLOGY

History of Sensor Technology

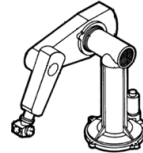


Stroke Rehabilitation Exerciser (2007)

Characteristics



Philips Research, Netherlands



A wireless inertial sensor system records the patient's movements

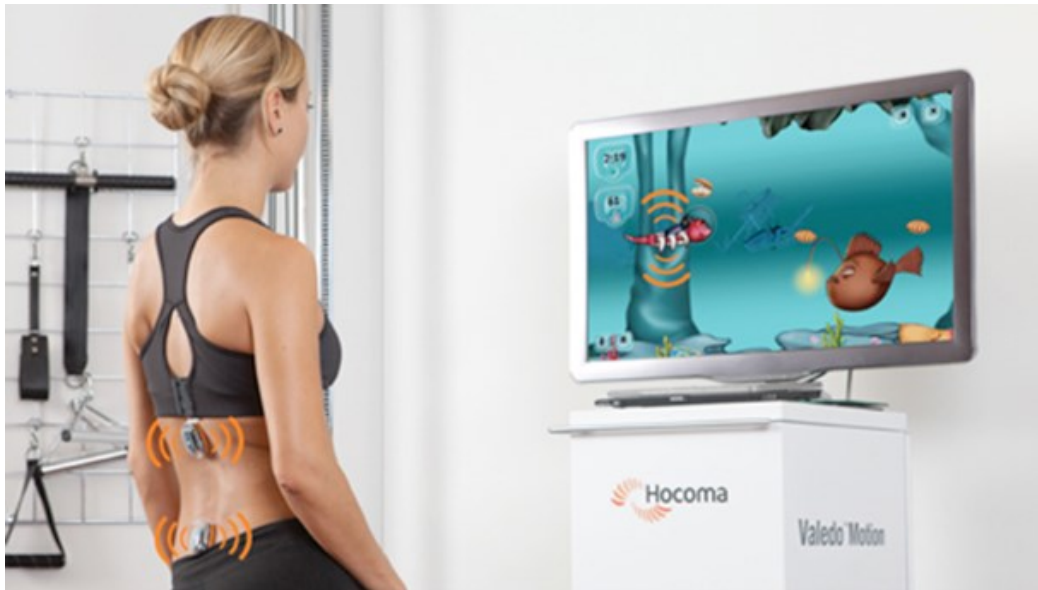
Data is automatically analyzed for deviations from a personal movement target and patient and therapist are provided with adequate feedback

i

Coaches the patient through a sequence of neurological motor exercises, which are prescribed by the physiotherapist and uploaded to a patient unit



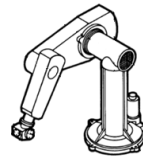
Valedo System (2011)



Characteristics



Hocoma AG in collaboration with the team led by Prof. Dr. Jan Kool at Zurich University of Applied Sciences in Winterthur, Switzerland



Wireless sensors attached to the patient's skin transfer even the smallest movements of the trunk and pelvis into a motivating game-like environment

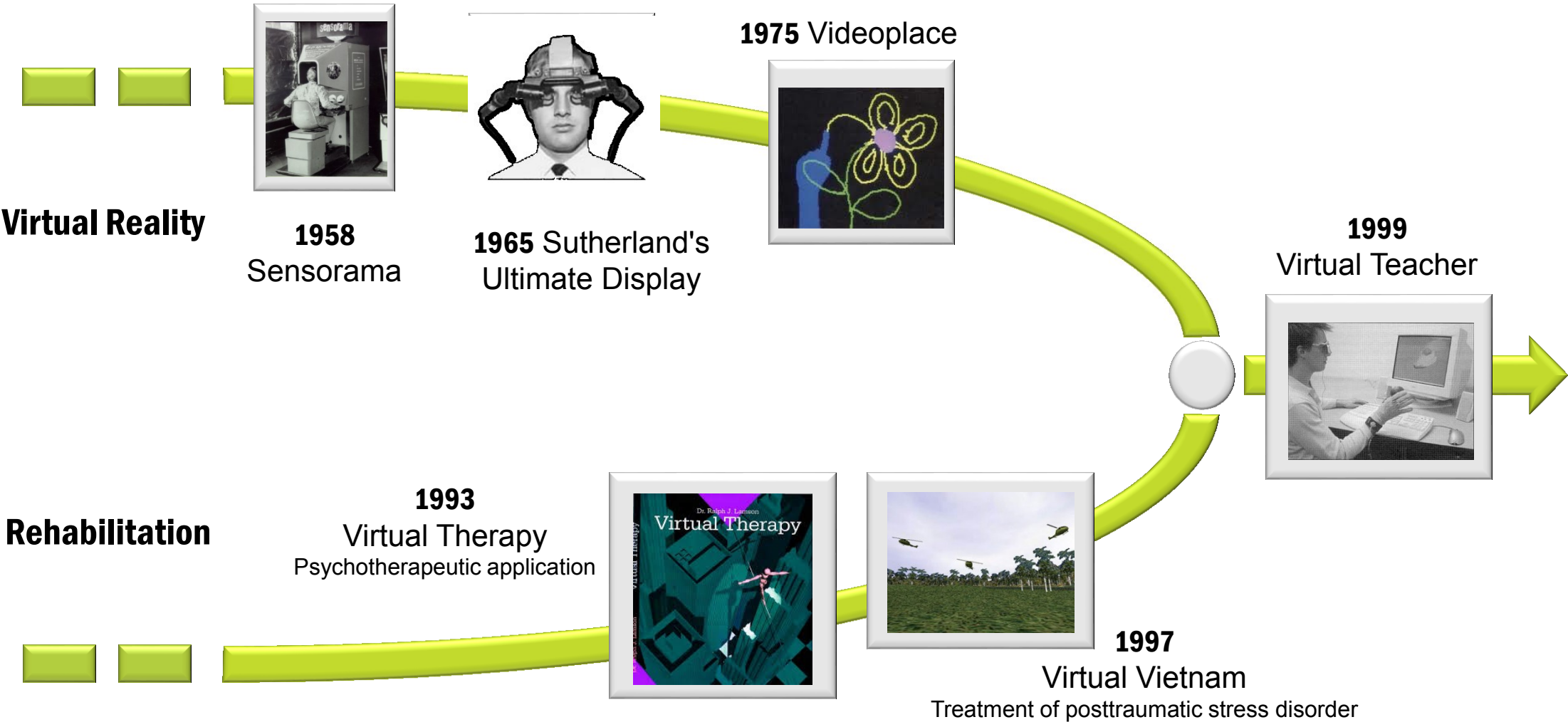
i

Exercises were designed to train specific therapeutic goals such as stabilization, mobilization and movement awareness

3.5

HISTORY OF VIRTUAL REALITY

Beginning of Virtual Reality



History of Virtual Reality

~ 1996



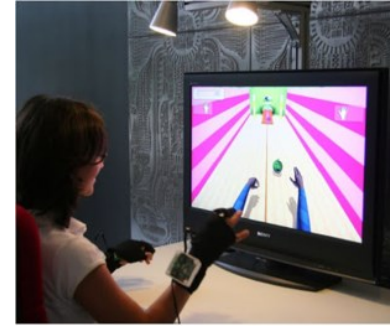
Vivid Group's Mandala
Gesture Extreme platform

~ 2001



Rutgers Ankle Reha Interface

~ 2009



Paediatric Interactive Therapy
System

Computer Assisted Rehabilitation
Environment (CAREN)



~ 2000

Rehabilitation Gaming
System (RGS)



~ 2007

Mandala Gesture Extreme platform (~ 1996)



Mandala Gesture Extreme platform
Vivid Group

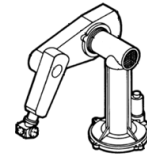
Characteristics



Platform together with a suite of interactive, game-type environments

Invented by a technology group in Toronto, Canada

Since ~1999 it has also begun to be adapted for use in rehabilitation



Subjects are immersed in a full-body virtual world where they can interact with on-screen images and objects, designed to enhance the sense of "presence" for the subject



GestureTek's Interactive Rehabilitation and Exercise System (IREX®)

CAREN (~ 2000)

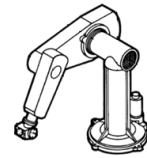


Computer Assisted Rehabilitation Environment
(CAREN)

Characteristics



In 1997, MOTTEK had applied for a research grant to the European commission. This grant was received in 1998 and enabled the development of the 1st prototype



Hydraulic 6 DOF motion base with ~700 kg payload, 2m diameter platform top with integrated dual force plates, 8 camera real-time motion capture system



The 1st production grade CAREN system was sold to the University of Groningen in 2000

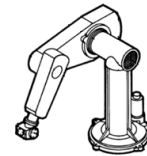
Rutgers Ankle Reha Interface (~ 2001)



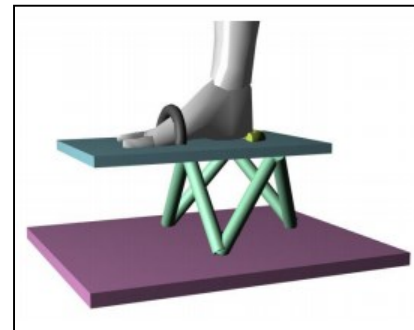
Characteristics



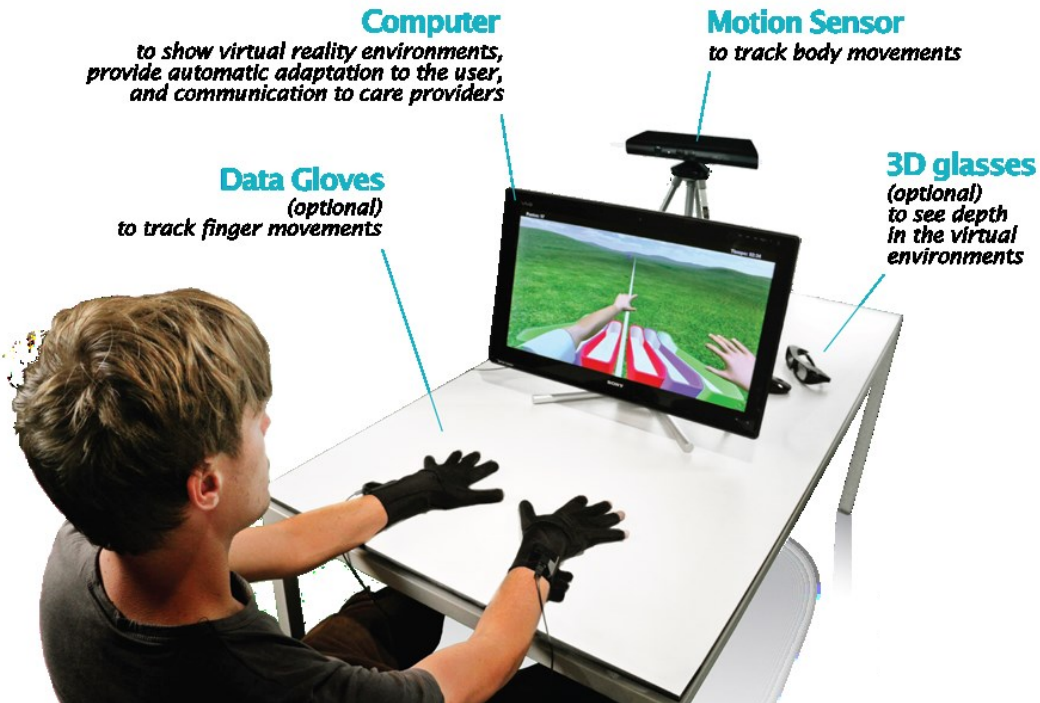
Designed for home use and internet-based remote monitoring by therapists. Invented by Rutgers, State University of New Jersey



Allows patient to interact with motivating virtual environments and allows movement in all 3 degree of freedom of the ankle



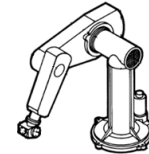
Rehabilitation Gaming System (~ 2007)



Characteristics



SPECS research group, University Pompeu Fabra
Hospital of Vall d'Hebron, Spain
Hospital de la Esperança, Spain



Tracking of arm movements with a Kinect sensor mounted on
top of the display
Two data gloves detect finger movements

i

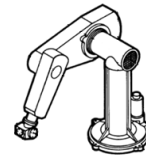
Movement execution is combined with the observation of
correlated actions performed by a virtual body

Paediatric Interactive Therapy System (~ 2009)

Characteristics



PITS is an applicable VR-system which can be feasibly applied during the rehabilitation of children with upper limb motor dysfunctions. It was invented by Rehabilitation Centre University Children's Hospital Zurich.



Consists of a pair of therapy-optimized data gloves with integrated movement tracking.

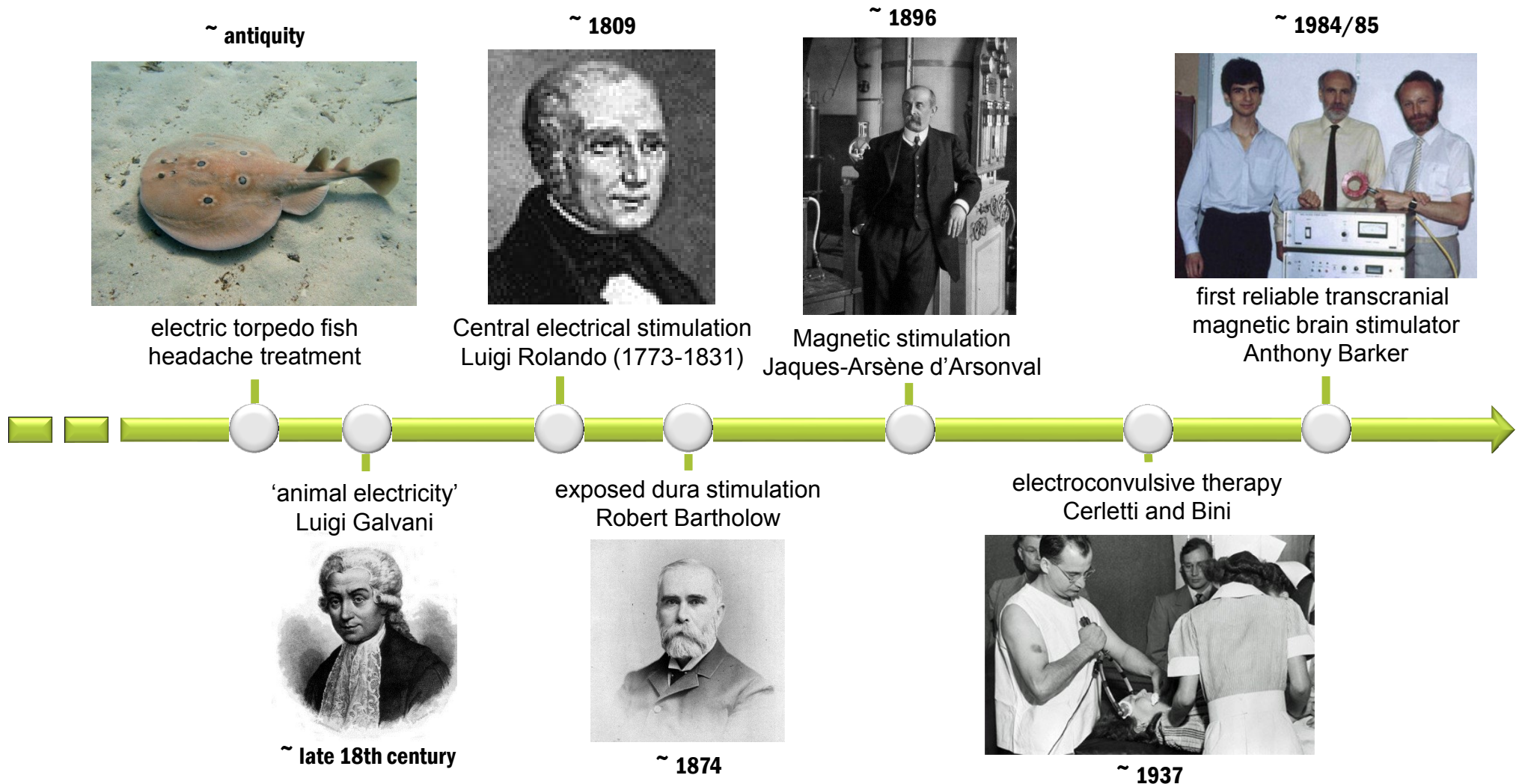


YouGrabber

3.6

HISTORY OF BRAIN STIMULATION

Beginning of Brain Stimulation



Sheffield Magnet (~ 1985)

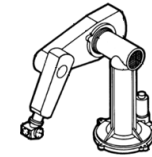


Sheffield Magnet

Characteristics



Barker et al., Sheffield University



54 μ F Mylarfilm capacitor, 4000 V



Magstim

International Industry Society in Advanced Rehabilitation Technology (IISART)

General Information

info@iisartonline.org

www.iisartonline.org

Image sources

Slide 2 – Audience

Background: http://www.iisd.ca/ymb/climate/wcc3/pix/lsept/DSC_6266%20full%20room.jpg

Slide 6 – Rehabilitation ...

Left image (massage): http://www.physio-pedia.com/images/7/74/Shoulder_massage.jpg

Right image (therapy): http://ottobock-export.com/cps/rde/xbcr/ottobock_export_en/gallery-large-en-rehaobex5.jpg

Slide 7 – History of Rehabilitation

1st image (hydrotherapy): http://www.bullfrogspas.com/uploads/images/home/1318031596_9.jpg

2nd image (Hippocrates): <http://www-tc.pbs.org/wgbh/nova/assets/img/hippocratic-oath-today/image-01-small.jpg>

3rd image (massage): http://www.physio-pedia.com/images/7/74/Shoulder_massage.jpg

4th image (Galen): <http://www.general-anaesthesia.com/images/galen.jpg>

5th image (Paré): http://upload.wikimedia.org/wikipedia/commons/6/6a/Ambroise_Par%C3%A9.jpg

6th image (mech. hand): <http://www.christianhubert.com/writings/Prosthesis1.jpeg>

7th image (Regard): http://upload.wikimedia.org/wikipedia/commons/c/cf/Possible_portrait_of_Nicolas_Andry.jpg

8th image (orthopaedics): http://www.cfdm.fr/images/Andry_1741_1.jpg

9th image (Tissot): http://upload.wikimedia.org/wikipedia/de/3/3f/WP_Joseph_Cl%C3%A9ment_Tissot.jpg

Slide 8 – History of Rehabilitation

1st image (gymnasticon): <http://upload.wikimedia.org/wikipedia/commons/4/42/Gymnasticon.png>

2nd image (Ling): http://upload.wikimedia.org/wikipedia/commons/8/8f/Pehr_Henrik_Ling.jpg

3rd image (Zander): http://c4.staticflickr.com/8/7181/7141664711_4d41445947_b.jpg

4th image (vacuum tube): http://c4.staticflickr.com/4/3345/3299295807_279a3db65b_z.jpg

5th image (Rusk): http://shs.umsystem.edu/historicmissourians/name/r/rusk/images/large/rusk_main_lg.jpg

Image sources

Slide 8 – History of Rehabilitation

6th image (Cybex I):

<http://www.isokinetics.net/images/stories/cybex1.jpg>

Slide 9 – Rehabilitation

1st image (crutches):

<http://ids.lib.harvard.edu/ids/view/20458087?width=3000&height=3000>

2nd image (wheelchairs):

<http://blog.targethealth.com/wp-content/uploads/2011/06/20110613-1.jpg>

3rd image (walkers):

http://image.ec2l.com/image/gentryway/oimg_GC04421974_CA04421975/Walking_Aid_Walker.jpg

4th image (prosthetic toe):

http://i.livescience.com/images/i/000/003/981/i02/070727_wood_toe_02.jpg?1296081730

5th image (iron hand):

http://news.bbcimg.co.uk/media/images/58793000/jpg/_58793348_1.jpg

Slide 10 – Rehabilitation

Images:

Presentation from Robert Riener

Slide 11 – Manual Arm Therapy

Slide:

Lecture slide from Robert Riener

Slide 12 – Conventional Gait Therapy

Slide:

Lecture slide from Robert Riener

Slide 14 – Technology...

Left image (handaxe):

http://humanorigins.si.edu/sites/default/files/images/portrait/3.3.4-30_handaxe_bose_jdhd_p.jpg

Right image (atlas):

[http://en.wikipedia.org/wiki/Atlas_\(robot\)#mediaviewer/File:Atlas_frontview_2013.jpg](http://en.wikipedia.org/wiki/Atlas_(robot)#mediaviewer/File:Atlas_frontview_2013.jpg)

Image sources

Slide 15 – History of Technology

1st image (aristotle):	http://johnnyholland.org/wp-content/uploads/aristotle0.jpg
2nd image (rooster):	http://daggy.name/carillon/batmbook/glcknspl.gif
3rd image (sheep mach.):	Lecture from Rod Grupen, <i>Foundations of robotics</i>
4th image (digesting duck):	http://www.paristechreview.com/wp-content/uploads/2013/07/220px-Vaucanson_duck1.jpg
5th image (writer of droz):	Lecture from Rod Grupen, <i>Foundations of robotics</i>
6th image (mech. knight):	http://upload.wikimedia.org/wikipedia/commons/thumb/4/45/Leonardo-Robot3.jpg/800px-Leonardo-Robot3.jpg
7 & 8th image (maillardet):	Lecture from Rod Grupen, <i>Foundations of robotics</i>
9 & 10th image (boilerpl.):	Lecture from Rod Grupen, <i>Foundations of robotics</i>

Slide 16 – History of Technology

1st image (R.U.R.):	Lecture from Rod Grupen, <i>Foundations of robotics</i>
2nd image (Capek):	Lecture from Rod Grupen, <i>Foundations of robotics</i>
3rd image (electro):	Lecture from Rod Grupen, <i>Foundations of robotics</i>
4th image (Asimov):	Lecture from Rod Grupen, <i>Foundations of robotics</i>
5th image (UNIMATE):	http://www.prsrobots.com/196lunimate.jpg
6th image (WABOT-I):	http://www.humanoid.waseda.ac.jp/booklet/photo/WABOT-I-1973.jpg
7th image (SCARA):	http://www.robotics.org/userassets/riauploads/hm_hs-white.jpg

Slide 17 – Early Active Orthoses

1st image (wind up):	From Dollar and Heer 2008, <i>Lower extremity exoskeletons and active orthoses: challenges and state-of-the-art</i>
2nd image (complete exo.):	From Dollar and Heer 2008, <i>Lower extremity exoskeletons and active orthoses: challenges and state-of-the-art</i>
3rd image (Wisconsin exo.):	From Dollar and Heer 2008, <i>Lower extremity exoskeletons and active orthoses: challenges and state-of-the-art</i>
4th image (Wisconsin exo.):	http://cyberneticzoo.com/wp-content/uploads/file/seireg2.jpg

Image sources

Slide 18 – Powered Exoskeletons

1st image (Yagn): From Dollar and Heer 2008, *Lower extremity exoskeletons and active orthoses: challenges and state-of-the-art*

2nd image (Hardiman): From Dollar and Heer 2008, *Lower extremity exoskeletons and active orthoses: challenges and state-of-the-art*

3rd image (Bleex): From Dollar and Heer 2008, *Lower extremity exoskeletons and active orthoses: challenges and state-of-the-art*

4th image (HAL): <http://cdn.slashgear.com/wp-content/uploads/2010/12/Cybyerdyne-HAL.jpg>

5th image (HAL): <http://cdn.slashgear.com/wp-content/uploads/2010/12/Cybyerdyne-HAL.jpg>

Slide 21 – Beginning of Robotic Rehabilitation

1st image (UNIMATE): <http://www.prsrobots.com/196lunimate.jpg>

2nd image (PUMA): <https://www.robotics.tu-berlin.de/typo3temp/pics/6/6ld47434le.jpg>

3rd image (SCARA): http://www.robotics.org/userassets/riauploads/hm_hs-white.jpg

4th image (mov. therapy): Lecture from Robert Riener

5th image (MIT-Manus): <http://www.jneuroengrehab.com/content/figures/1743-0003-1-5-1.jpg>

Slide 23 – Upper Limbs Therapeutic Robots

1st image (MIT-Manus): <http://www.jneuroengrehab.com/content/figures/1743-0003-1-5-1.jpg>

2nd image (MIME): From Burgar et al. 2000, *Development of robots for rehabilitation therapy: The Palo Alto VA/Stanford experience*

3rd image (ARM Guide): From Reinkensmeyer et al. 2000, *Understanding and treating arm movement impairment after chronic brain injury: Progress with the ARM Guide*

4th image (Gentle/S): http://www.gentle.rdg.ac.uk/103-0325_IMG.JPG

5th image (Bi-Manu-Track): <http://stroke.ahajournals.org/content/43/10/2729/F1.large.jpg>

6th image (NeReBot): <http://cono-scienza.fisica.unipd.it/pics/nerebot.jpg>

7th image (ARMin): http://manokel.com/eng/img/eng_3a.jpg

with the ARM

Image sources

Slide 32 – Beginning of Robotic Rehabilitation

- 1st image (Hardiman): From Dollar and Heer 2008, *Lower extremity exoskeletons and active orthoses: challenges and state-of-the-art*
2nd image (man. training): Hocoma
3rd image (Lokomat): Hocoma

Slide 33 – Lower Limbs Therapeutic Robots

- 1st image (Lokomat): Hocoma
2nd image (Gait Trainer): <http://www.reha-stim.de/cms/assets/images/GT-l-mit-Person>
3rd image (ReoAmbulator): http://www.upsite.co.il/uploaded/images/1357_4e7015bf77f343278c10f3ff0d7dcd48.png
4th image (Lopes): <http://www.utwente.nl/ctw/bw/RESEARCH/PROJECTS/LOPES/lopes-4.jpg>
5th image (Haptic Walker): From Schmidt 2004, *Haptic Walker - A novel haptic device for walking simulation*

Slide 34 – Lower Limbs Therapeutic Robots

- 1st image (PowerKnee): <http://cdn.medgadget.com/img/balleg.jpg>
2nd image (ALEX): <http://roar.me.columbia.edu/projects/alex/figures/alex.png>
3rd image (Anklebot): <http://www.jneuroengrehab.com/content/figures/1743-0003-7-23-1.jpg>
4th image (G-EO-System): http://img.medicaexpo.de/images_me/photo-mg/computerbasiertes-rehabilitationssystem-69821-3665809.jpg

Slide 41 – Beginning of Non-Actuator Devices

- 1st image (MIT-Manus): <http://www.jneuroengrehab.com/content/figures/1743-0003-1-5-1.jpg>
2nd image (MIME): From Burgar et al. 2000, *Development of robots for rehabilitation therapy: The Palo Alto VA/Stanford experience*
3rd image (ARM Guide): From Reinkensmeyer et al. 2000, *Understanding and treating arm movement impairment after chronic brain injury: Progress Guide*
4th image (mov. therapy): Lecture from Robert Riener
5th image (T-WREX): http://docs.exdat.com/data/46/45284/45284_html_m46c7b26d.jpg

with the ARM

Image sources

Slide 42 – History of Non-Actuator Devices

1st image (GBD): From Banala et al. 2004, *A Gravity Balancing Leg Orthosis for Robotic Rehabilitation*

2nd image (T-WREX): http://docs.exdat.com/data/46/45284/45284.html_m46c7b26d.jpg

3rd image (Freebal): <http://www.utwente.nl/ctw/bw/research/projects/ar/ar-4.jpg>

4th image (Dampace): From Prange et al. 2010, *An explorative, cross-sectional study into abnormal muscular coupling during reach in chronic*

stroke patients

5th image (handSOME): <http://cabrr.cua.edu/res/images/research/Handsomepic6.jpg>

6th image (ZeroG passive): <http://www.aretechllc.com/img/passive/zgpl-n.jpg>

Slide 48 – History of FES

1st image (Liberson): <http://patentimages.storage.googleapis.com/US20030144710A1/US20030144710A1-20030731-D00001.png>

2nd image (Parastep I): <http://www.musclepower.com/images/sitstand-l.jpg>

3rd image (Freehand Sys.): http://www.surgicalneurologyint.com/articles/2011/2/1/images/SurgNeurolInt_2011_2_1_121_84392_u2.jpg

4th image (Bionic Glove): http://t0.gstatic.com/images?q=tbn:ANd9GcRtfm8y5vSLuL097cIBNGqF2Vitnkz8h5N8Q0gL_uL3mY-chD3T

5th image (Handmaster): From Snoek et al. 2000, *Use of the NESS Handmaster to restore handfunction in tetraplegia: clinical experiences in ten*

patients

6th image (Complex Mot.): http://control.ee.ethz.ch/~ncg/previous_projects/images/fes_tim_03.jpg

Slide 57 – History of Sensor Technology

1st image (life alert): <http://protection.com/images/PhoneBG.png>

2nd image (AMON): http://art-of-technology.ch/typo3temp/pics/AMON_d107c70ad0.jpg

3rd image (LiveNet): From Sung et al. 2005, *Wearable Feedback Systems for Rehabilitation*

4th image (Exerciser): http://blogs.iad.zhdk.ch/ba-methods-2011/files/2011/01/Philips_Stroke_Rehab_Exerciser.jpg

5th image (Wellcore): <http://cdn.ubergizmo.com/photos/2010/1/wellcore-base-468.jpg>

6th image (Valedo): <http://www.lucamed.de/files/6d3e138cb0.jpg>

Image sources

Slide 73 – Beginning of Brain Stimulation

1st image (torpedo fish):	http://upload.wikimedia.org/wikipedia/commons/d/df/Torpedo_torpedo_corsica2.jpg
2nd image (Luigi Galvani):	http://upload.wikimedia.org/wikipedia/commons/3/39/Luigi_galvani.jpg
3rd image (Rolando):	http://www.cerebromente.org.br/nl8/history/foto1_small.jpg
4th image (Bartholow):	http://chillopedia.com/wp-content/uploads/150px-Roberts_Bartholow.jpg
5th image (d'Arsonval):	http://upload.wikimedia.org/wikipedia/commons/2/2d/Jacques-Ars%C3%A8ne_d%27Arsonval.jpg
6th image (electroconvul.):	http://s.hswstatic.com/gif/electroconvulsive-therapy-1.jpg
7th image (Barker):	http://www.magstim.com/img/imagecache/e/c/b/c/cache_ecbc4863b8c05a2dd477b86699ad67a0.jpg