Taxonomy of rehabilitation robotics

- rehabilitation robotics: *therapy* and *assistance* robots…
  - Operational Therapy Robots (or End-Effector-Based Therapy Robots)
    - trajectories of robot/human end-effector (hand or foot) are physically coupled in the operational space
    - joint space trajectories can be significantly differ
  - pros
    - designed by using off-the-shelf components/robots
    - easily programmed in Cartesian space by non-expert users
  - cons
    - not able to assist each single human joint independently
    - patients using these robots are supposed to feature a minimum level of residual motor synergies

MIT manus

- one of the first rehabilitation-therapy robots
- commercial product sold by Interactive Motion Technologies
- developed by Hogan, Krebs, at the Massachusetts Institute of Technology (USA)
- two-joint robot arm that assists and measures planar reaching movements
- position controller with an adjustable impedance
- vertical motion, wrist motion, grasp, virtual environment
- used to analyze different types of therapies
  - to compare assisting movement versus resisting movement
- the robot-assisted therapy group improved their movement ability more than the usual care
- cost benefit

https://www.youtube.com/watch?v=EN5_24biEWU

MIME (mirror-image movement enhancer)

- Puma-560 robot arm to assist in movement of the patient's arm
- end-effector attached to the patient hand (connector designed to break away if interaction forces become too large)
- more naturalistic motion of the arm because of its six degrees of freedom
- must rely on force feedback so that the patient can drive the robot arm
- four control modes were developed
  - passive mode: the patient relaxes and the robot moves the arm through a desired pattern
  - active assist mode: the patient initiates a reach toward a target which then triggers a smooth movement of the robot toward the target
  - active-constrained mode: the device allows movement toward the target but prevents the patient from moving away from the target
  - mirror image mode: the motion of the patient's less impaired arm is measured with a digitizing linkage, and the impaired arm is controlled to follow along in a mirrors symmetric path

http://handbookofrobotics.org/view-chapter/64/videodetails/495

Taxonomy of rehabilitation robotics

- rehabilitation robotics: *therapy* and *assistance* robots…
  - Wearable Therapy Robots (or Exoskeleton-Based Therapy Robots)
    - a larger portion of the human body (typically the whole affected limb) is in continuous physical contact with the robot
    - the trajectories of the robot joints approximate those of the human joints
  - pros
    - possibility of sensing the configuration and assisting each human joint independently
  - cons
    - additional design considerations
      - to avoid misalignments between robot and human joints
      - to minimize the invasiveness for the patient: weight, dimensions, and overall wearability
- the ARMin is controlled by a joint-based guidance algorithm which enforces normal coordination between shoulder and elbow joints.

http://handbookofrobotics.org/view-chapter/64/videodetails/497

Taxonomy of rehabilitation robotics

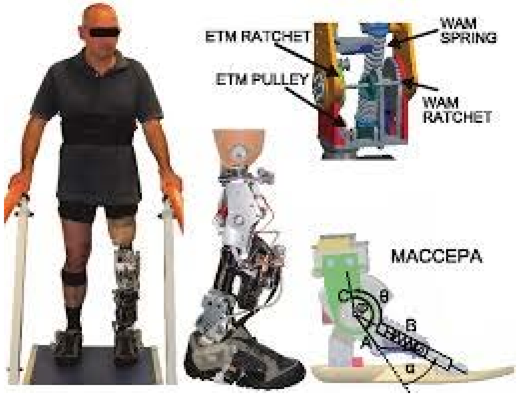
- rehabilitation robotics: *therapy* and *assistance* robots…
  - Non-Contact Therapy Robots (or Socially Assistive Robotics)
    - do not physically contact the patient, but instead monitor and coach the patient during therapy
    - Intrinsically safe, since they are not supposed to physically interact with the patient
- assistive robots…are solutions for promoting independent living of disabled and elderly citizens
  - manipulation
    - fixed-platform – kitchen/desktop/bed
    - portable-platform – arms attached to an electric wheelchair
    - mobile-platform – autonomous robots
  - mobility (electric wheelchairs and mobile robots that act as smart motorized walkers) helping for mobility impairements
  - cognitive (assists dementia, autism, communication problems)

Assistive robots

- Wheelchair
  - EMG control (https://www.youtube.com/watch?v=L3mPMQbJs6Q)
  - telemanipulation control (https://www.youtube.com/watch?v=iZYxJFROew8)
- Cognitive
  - Paro (https://www.youtube.com/watch?v=oJq5PQZHU-I)
- Social
  - Pepper (https://www.youtube.com/watch?v=3PPEpybFSdg)
    (https://www.youtube.com/watch?v=oDeQCIkrLvc)

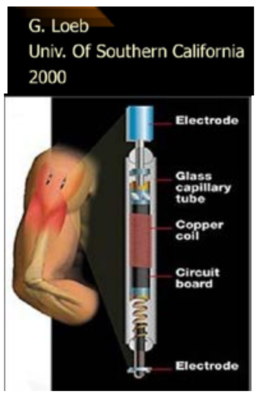
…in addition

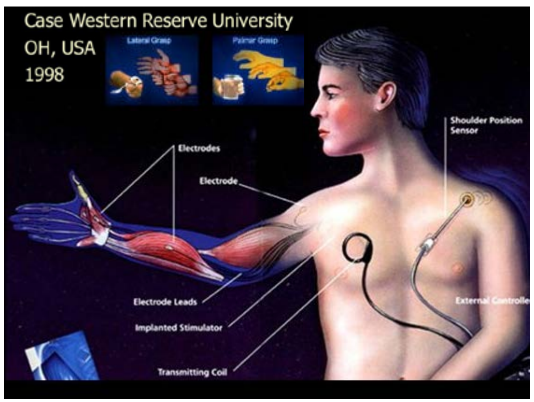
- artificial limb (prosthetics) development

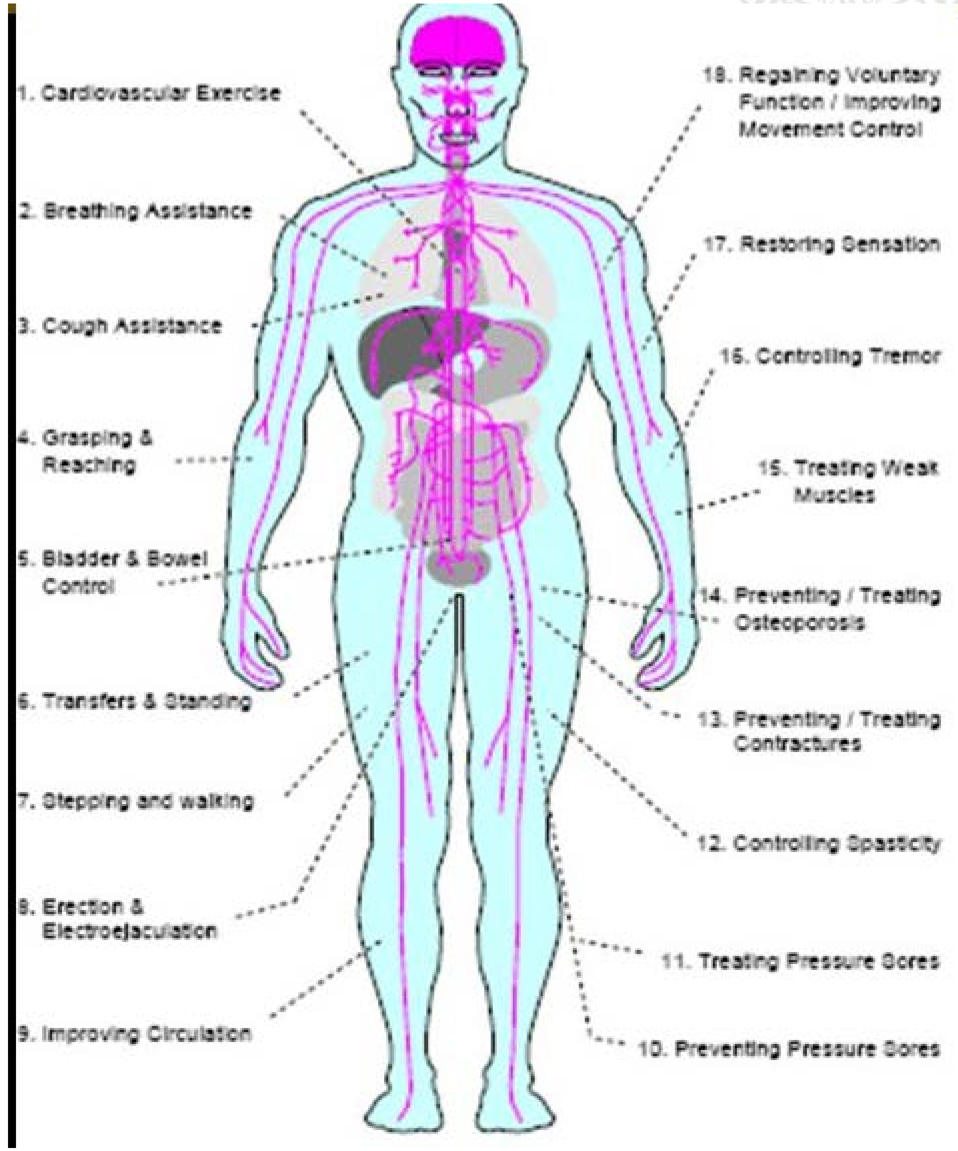


…in addition

- functional neural stimulation (FNS)
  - technique that uses low energy electrical pulses to artificially generate body movements in individuals paralyzed due to injury to the central nervous system

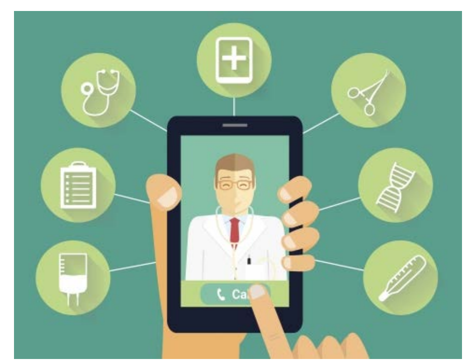






…in addition

- technology for diagnosis and monitoring of people during activities of daily living (advanced materials and nanotechnologies)
  - in-home diagnostic equipment and in-home robot-assisted therapy
    - smart homes
    - devices to kept informed on the status of the disabled person (sent regular vital signs and other medical/therapy reports
    - tele-health services
  - devices worn on or in the body for vital signs monitoring
    - endoscopic capsula (to record internal images of the gastrointestinal tract for use in medical diagnosis)
    - LifeShirt collects information on a range of cardiopulmonary parameters (front-line soldiers and rescue operation personnel)



Wearable robots

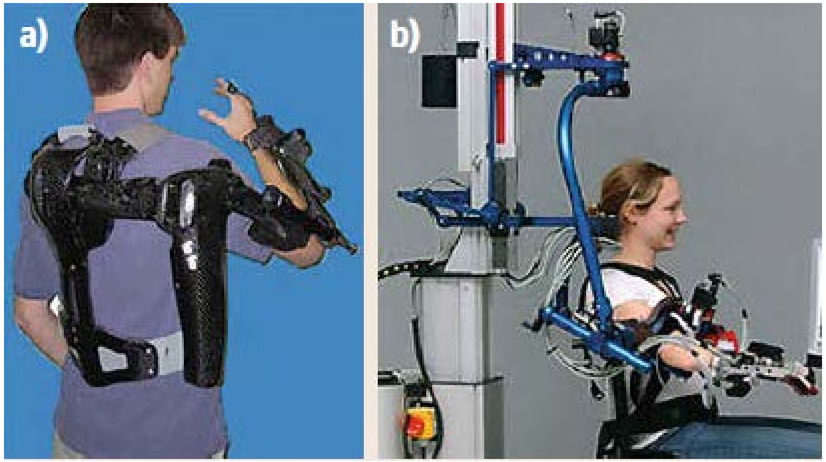
- the concept of human–robot augmentation refers to the use of robotics systems to increase human functionalities in different operational contexts (decrease fatigue and increase safety)
  - level of loads
  - high number of repetitions
- physical structure which is always in contact with the human operator's body during operation
- strong contribution from haptic interfaces, i. e., robotic systems that are able to generate forces on the human body (force feedback)
- recent developments: exoskeletons in neurorehabilitation
  - the robotic system is used to kinetically assist the patient's limb during the performance of specific exercises

Wearable robots

- wearable robotics systems for human augmentation can be divided into three different categories:
  - prostheses for the functional replacement of human limbs
  - powered orthoses, whose function is to actively operate in parallel with unhealthy human joints
  - robotic exoskeletons that operate in parallel with human limbs

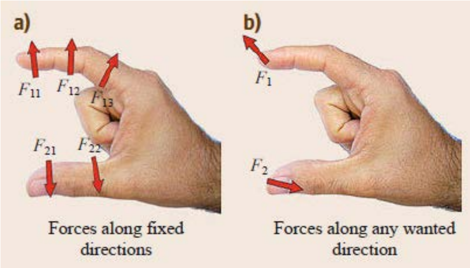
Upper limb wearable systems

- are placed in parallel and work in concert with the human arm
- exoskeletons with up to 9-DOFs have been developed for the shoulder–elbow–wrist–finger complex
- exoskeletons with up to 18-DOFs have been developed for the wrist–finger complex

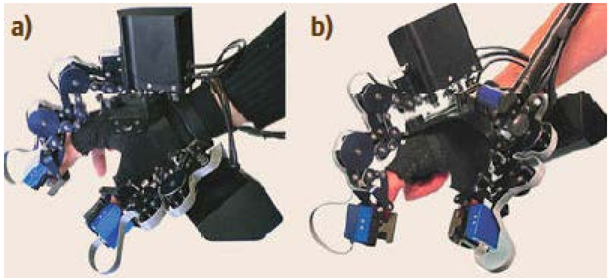


Hand exoskeleton

- multiphalanx hand exoskeletons (MPHE)
  - able to exert different forces on at least two of the phalanges of the same finger
  - usually the force can be applied on a fixed direction normal to the phalanx axis
- single-phalanx hand exoskeletons (SPHE) are able to exert forces on one phalanx of the finger (distal)
  - force only along a fixed direction
  - forces with any desired orientation



- anthropomorphic devices
- non anthropomorphic devices



Applications

- teleoperation and virtual environments in which the HE are utilized as master controllers providing force feedback
- neurorehabilitation, in which HE are used for restoring hand functionalities after strokes
- space applications in which HE are employed as active devices for extending grasping forces of the astronauts in extra vehicular activities

https://www.youtube.com/watch?v=kgSv7zcpeE8

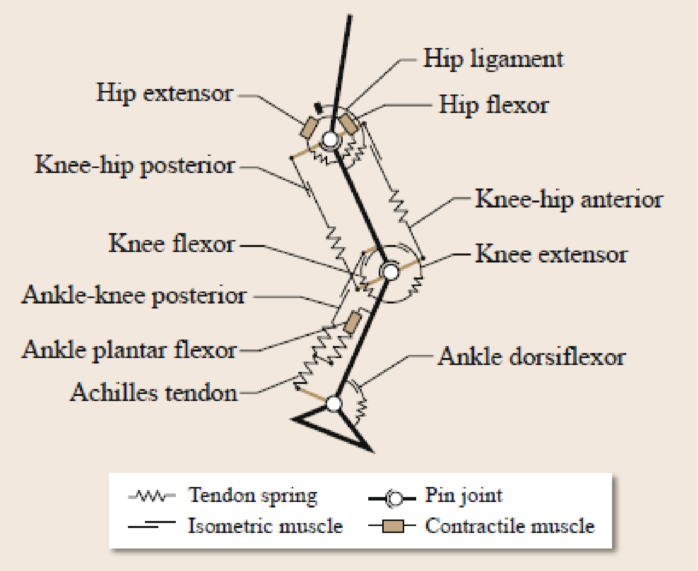
https://www.youtube.com/watch?v=Lgb1x7P3Anw

Actuation methods

- hydraulic motors
  - very large power-to-weight ratio
  - high stiffness
  - direct-drive operation
  - low energetic efficiency
  - bulky, high pressure fluid components (power supply, valves, and tubing)
- pneumatic cylinders and muscles
  - large power-to-weight ratio
  - direct-drive operation
  - low energetic-efficiency
  - low stiffness
  - slow and nonlinear response
  - bulky and noisy fluid components (power supply, valves and tubing)
  - can generate forces in one direction only
- electric motors
  - very efficient
  - easy to control
  - good power-to-weight ratio
  - work better at high speeds
  - rarely used in direct-drive operation, but rather they are combined with either standard gearboxes or harmonic drives

Lower limb wearable systems

- *active leg orthosis* is typically used to describe a device that is used to increase the capacity of a person suffering from leg pathology to ambulate
- *leg exoskeleton* is used to describe a device that augments the locomotory performance of an able-bodied wearer



Control of human-robot augmentation

- the functionality of a power augmentation system should simultaneously provide
  - force amplification (upper-body)
    - enhances human manipulation abilities through the multiplication of the arm forces during grasping operations of heavy loads
  - support to natural locomotion (lower-body)
    - cooperates with a human gait, while sustaining much of the body loads
    - keeping overall equilibrium and following the human motion with transparent and natural reflection forces

Control of human-robot augmentation

- *stability*: the stability margin of the (linearized) control system should be large enough to cope with the environment and operator uncertainties, and to avoid uncompensated oscillations entering into resonance with the human postural control
- *transparency*: the system should (through mechanical design or sensor augmentation) allow a correct perception of the overall interaction with the environment and a proper generation of the control actions
- r*egular force amplification*: the gain ratio of the human force amplification should be kept as regular as possible in all interaction conditions
- f*ast response*: the bandwidth and the saturation values of the position/velocity/force controllers should be as close as possible to their respective ranges used in natural motions and interaction

10 exoskeleton
https://www.youtube.com/watch?v=GH3vVUUQDT4