ROBOT-ASSISTED REHABILITATION (I)
UPPER-LIMB REHABILITATION

職能治療學系
陳信壅

Robot-Assisted Rehabilitation: State of Art

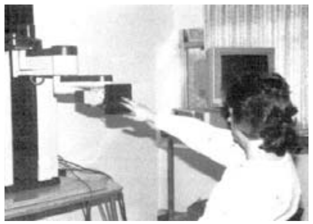
- Relieve the drawbacks of the traditional rehabilitation interventions
  - lack of repeatability
  - short training sessions
  - assessment only based on observation
- Aims
  - safely facilitate the restoration of abilities by providing a task-oriented and repetitive training and monitoring the patient progresses

Types of Therapeutic Movement

- Passive movement
  - outside force is completely responsible for the movement
- Active assisted movement
  - patient provides some effort, but also receives some assist from an outside force
- Active movement
  - patient provides the entire effort. No outside help is provided.
- Anti-gravity movement
  - motion that causes a body part to provide effort to move against the force of gravity
- Gravity reduced movement
  - motion is supported in some way and motion occurs perpendicular to the direction of gravitational force, sliding along the supporting surface

Robots for Rehabilitation

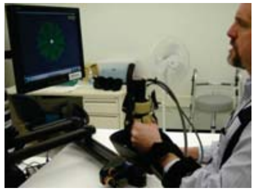
- Starting in early 1990s
- Serve as intelligent assistants for persons with high levels of impairment
- High cost, regulation policy, and reluctance were effective barrier

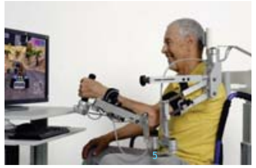


(Dijkers et al., 1991)

Classification of Rehabilitation Robot

- End-effector robots
  - human-robot interface attached at the distal part of the body
  - not constrain the kinematics of human joint but applies a force in the Cartesian space
- Exoskeletons
  - wrap around the human body
  - acting as an external, parallel skeletal and allow for independent control of each individual joint of their wearer
  - more complex and bulky kinematic structure





Energy Source for Mechanical Power

- Hydraulic motor
  - due to the inherent nature of being bulky, noisy, and prone to fluid leakages, the usage has been declining
- Pneumatic motor
  - lighter and quieter but still challenging to embed in a portable system since the compressor unit is quite heavy
  - Pneumatic artificial muscles (PAMs)
    - inflatable bladder that increase in diameter and shorter in length, required agonist-antagonist motion

Energy Source for Mechanical Power

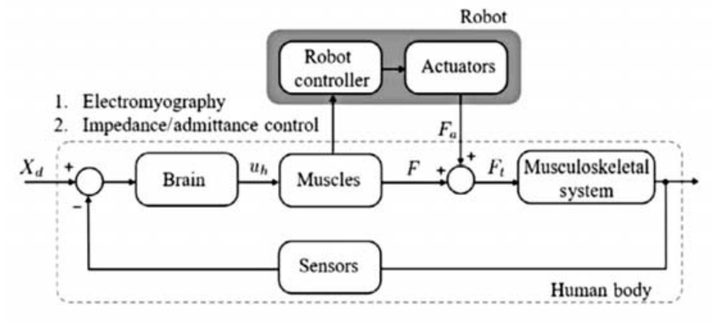
- Electric motor
  - high power density and ease of use
  - backdrivable system for safer interaction between humans and robots and in implementing control strategies
  - combine elastic element in series make it possible to lower the impedance levels and achieve a more accurate force control
    - advantage
      - ✓ securing safety and improved performance of force control
      - ✓ implemented on stiff actuators with impedance control
    - disadvantage
      - ✓ need of extra components and a deterioration of position control performance
      - ✓ lower position control due the input command is force/torque

Control Strategies

- Human-robot interaction control system
- Closed-loop impedance controller
- Admittance controller

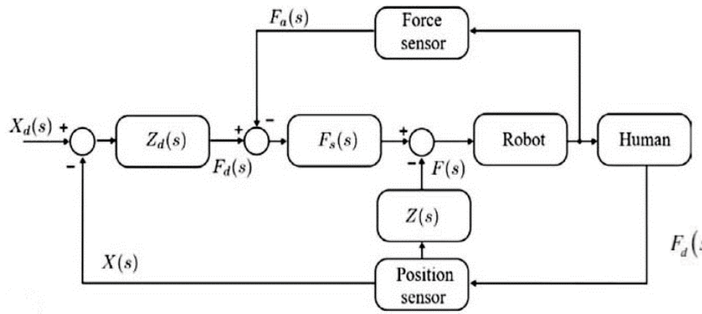
Human-Robot Interaction Control System

- Feedback loop, where the brain plays the role of controlling human motion



Closed-Loop Impedance Controller

- Define the desired impedance between a desired input position and the actuator force
- Requires the actuator to be backdrivable, relies on accurate modeling of the robot's dynamics, and is not suitable to render high impedances



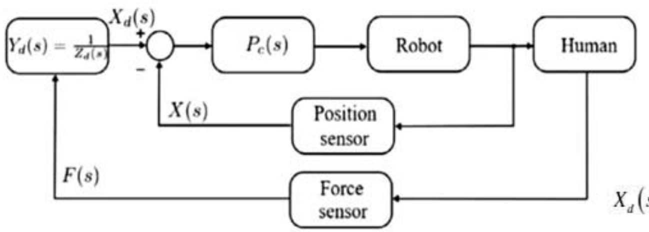
$$Z(s)=\frac{F(s)}{X(s)}=Ms^2+Bs+K$$

$$Z_d(s)=M_d s^2+B_d s+K_d$$

$$F_d(s)=\left(M_d s^2+B_d s+K_d\right)\left[X_d(s)-X(s)\right]$$

Admittance Controller

- Comprises an admittance-based trajectory generator and force sensor in a feedback loop
- Guarantee backdrivability by control
- Inner control loop is to accurately track the desired trajectory as fast as possible



$$X_d(s)=\frac{F(s)}{Z_d(s)}=\frac{F(s)}{M_d s^2+B_d s+K_d}$$

Position Control

- Trajectory tracking control
  - the basis for other strategies
  - achieve repeated passive training
  - trajectory generation and high control accuracy are key issues
  - essential in early rehabilitation
    - passive way
    - lack initiatives

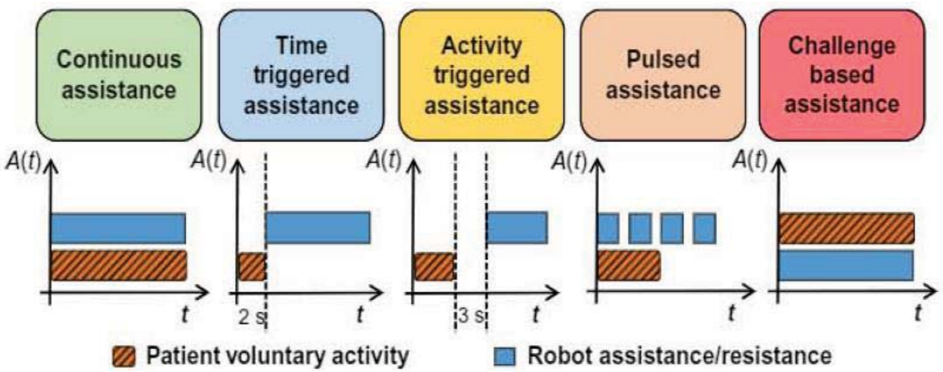
Force and Impedance Control

- Hybrid position/force control
  - divide the control into an independent position control loop and a force control loop
  - move along the desired trajectory and maintain certain interactive force
  - apply for strengthening exercises
- Impedance control
  - most appropriate approach for rehabilitation
  - regulate the dynamic relationship between robot position and contact force

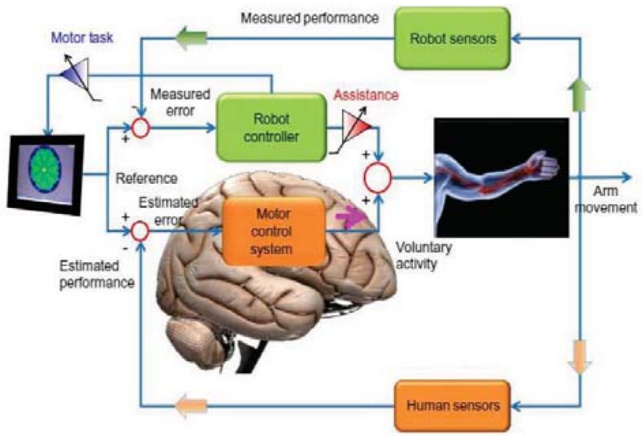
Adaptive Control

- Movement ability-based adaptive control
  - make the robot's behavior more flexible and adjustable to the patient's ability and participation, by active force or tracking errors
  - patient can take the maximum efforts without relying on robot
- EMG-based evaluation and adaptive control
  - enable the robot be controlled in a more natural way using muscles
  - build the relationship between EMG signals and muscle activity and adjust robot assistance level to recovery needs
- Assist-as-needed control
  - cooperative, adaptive, interactive control with patient's participations
  - adaptive to patient's needs and assist the movement only as much as needed
  - encourage maximal voluntary efforts

Assistance Modalities

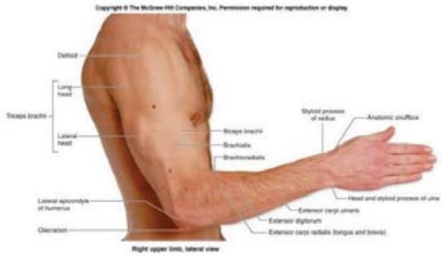


Regulation of Assistance



Robotic Devices for Upper limb Rehabilitation

- Proximal section
  - reaching movements involving the shoulder and elbow joints
- Distal sections
  - wrist, finger movements



End-Effector Robots for Hand Rehabilitation

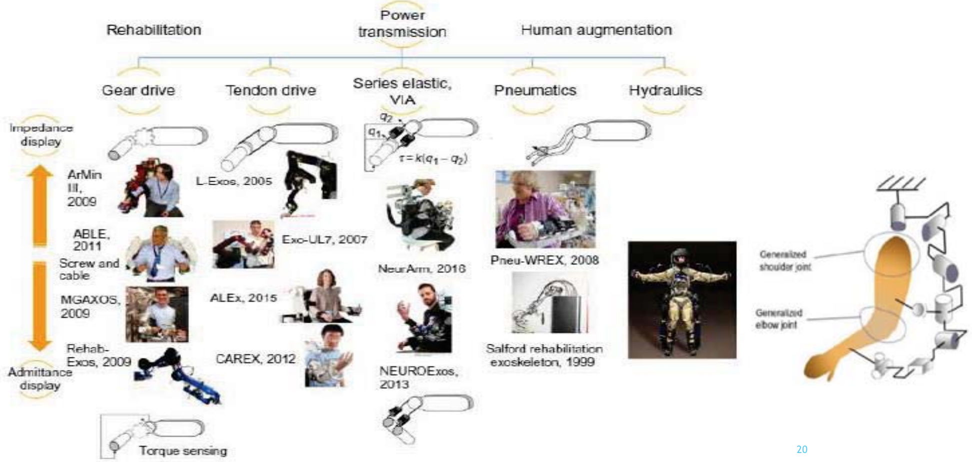
- Only supports the distal limb of the patient
- Weight support is often provided for the arm to reduce muscle fatigue
- Enabling a patient to focus on the hand function training
- Allow fitting of different size hands with minimum adjustment, thus setting up for a new patient is fast



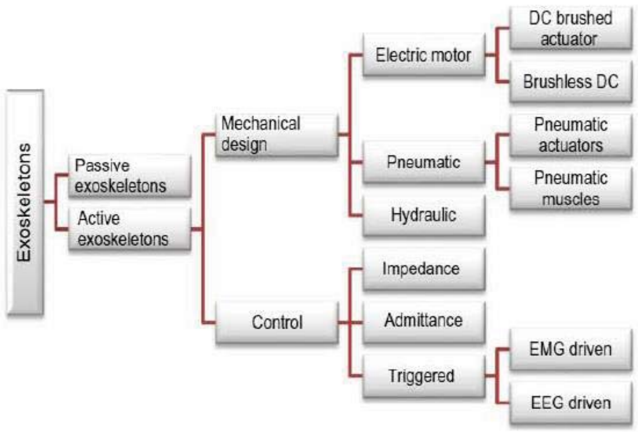
Exoskeleton for Upper Extremity Rehabilitation

- Not only the end effector of the human arm but also the full kinematic chain providing single-joint robotic assistance during movement
- Isomorphic to that of human arm and it appears like an outer structure covering the human arm

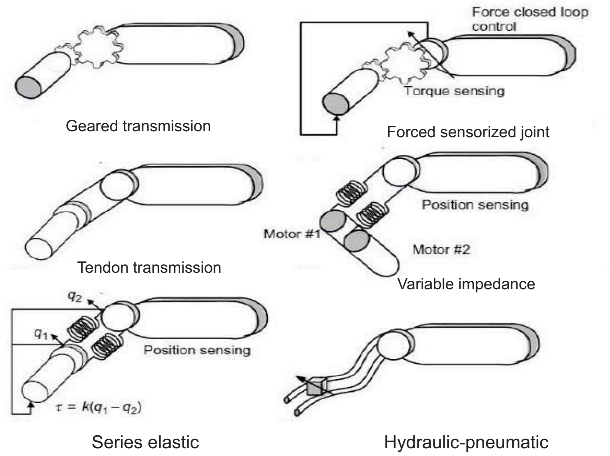
Design of Exoskeletons



Actuator and Controls for Designs of Exoskeletons



Principles of Actuation for Exoskeletons



Commercial Exoskeletons

Geared-drive design


AR Min III


ABLE exoskeleton


Rehab-Exo

Tendon drive design

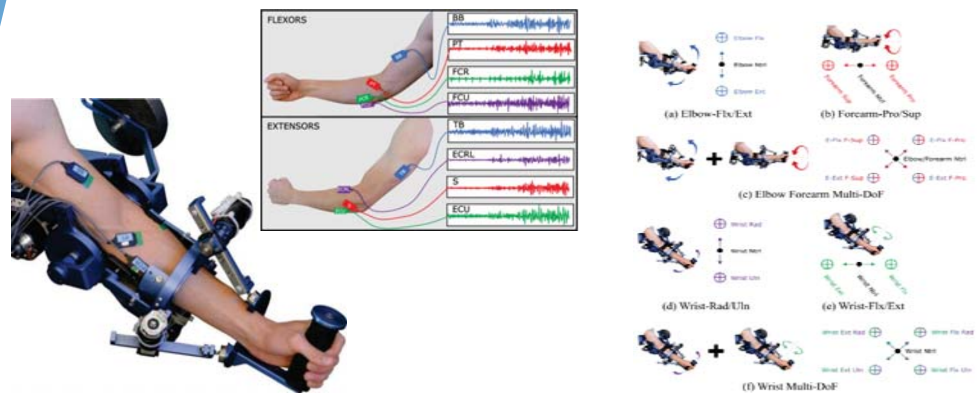

L Exos


EXO-UL77


ALEx

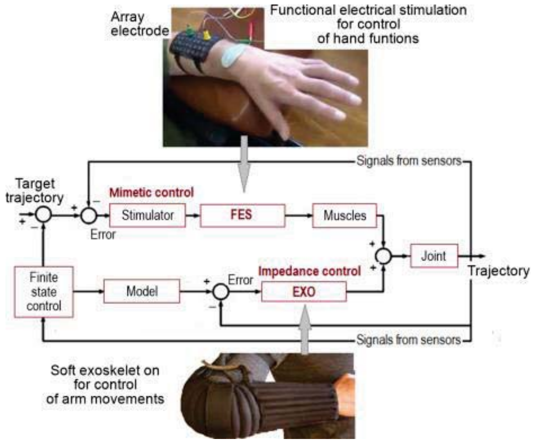

Soft-arm Compliant Exoskeleton

Myoelectric Control Interface for Upper-Limb Robotic Rehabilitation

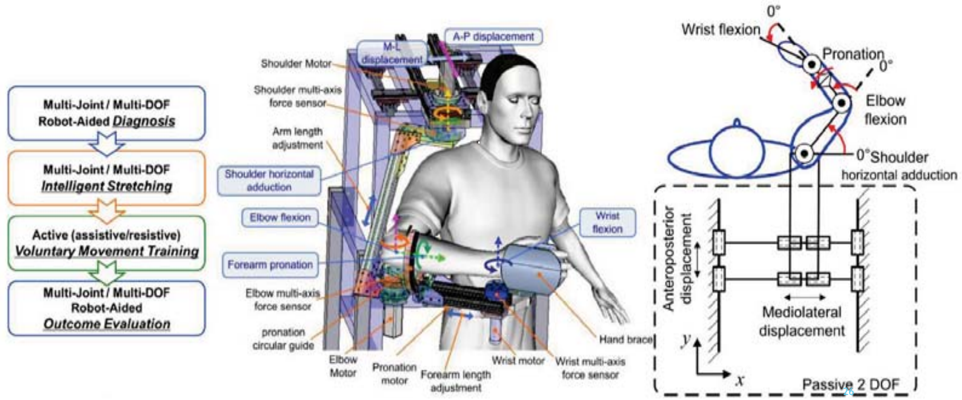


(McDonald et al., IEEE Trans Neural Sys Rehabil Eng, 2020)

Hybrid FES-Robot Device for Hand Rehabilitation



Multi-Joint Upper Limb Exoskeleton Robot



(Ren et al., IEEE Trans Neural Sys Rehabil Eng, 2013)