Upper Limb Exoskeletons for Stroke Rehabilitation

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Quiz (10 point)

• (4 pt) What is swivel angle?

• (6 pt) List at least 3 kinematic redundancy resolution criteria for predicting the natural reaching arm posture, and explain what they are.
Overview

- Stroke and Rehabilitation
- Upper Limb Exoskeletons for Stroke Rehabilitation
Stroke
Stroke

• A sudden interruption in the blood flow supplying oxygen and nutrients to brain tissue

• Consequence
  • Brain cell death
  • Partial loss of neurological function
Facts and Numbers [1]

• Stroke kills about 140,000 Americans each year—that’s 1 out of every 20 deaths

• Someone in the United States has a stroke every 40 seconds. Every 4 minutes, someone dies of stroke.

• Stroke costs the United States an estimated $34 billion each year. This total includes the cost of health care services, medicines to treat stroke, and missed days of work

• Stroke is a leading cause of serious long-term disability. Stroke reduces mobility in more than half of stroke survivors age 65 and over.
Stroke Recovery due to Neuroplasticity

- Neuropalsticity
- Short-term VS long-term
- Stroke recovery
  - Restitution
  - Substitution
  - Compensation
How much can be recovered?

- Full recovery is hard
  - 6-10% stroke survivals with severe paralysis achieve a **full recovery** after **6 months**
  - 18% of them regain full upper limb function

- How to achieve better recovery?
  - Exercise actively as much as one can
The Principles of Stroke Rehabilitation

- Active Engagement
  - Passive movements are insufficient to alter motor recovery

- Task-specific and context-specific training
  - Target at the patients’ needs
  - In patients’ own environments

- High intensity
  - No ceiling effect for therapy intensity
The Timing of Stroke Intervention

- **Stroke onset**
- **Spontaneous neurological recovery**

**Time**
- **Hours: medical**
- **Hours–days: early mobilisation**
- **Days–weeks: restoring impairments in order to regain activities**
- **Days–months: task-oriented practice with adaptive learning and compensation strategies**
- **Days–months: specific rehabilitation interventions (including physical fitness) to improve extended activities of daily living and social interaction**
- **Weeks–months: environmental adaptations and services at home**
- **Months–years: maintenance of physical condition and monitoring quality of life**
How to measure recovery?

• Commonly used methods
  • Fugl-Meyer (FM) score
  • Functional independence measure (FIM)
  • Motor power scale (MPS)
  • Motor status scale

• From qualitative to quantitative measurements
Upper Limb Exoskeleton for Stroke Rehabilitation
Advantages of Robot-assisted Rehabilitation

- Provide consistent training
  - Inconsistency due to therapist fatigue and other human factors

- Measure performance with higher reliability and accuracy

- Allow patients to train more independently with less supervision from a therapist
Categorization of Assistive Robots

- End-effector devices VS exoskeletons
- Unilateral VS Bilateral
- Exoskeleton
  - Partial VS Full
  - Single VS multi-robot
End-effector Devices

Unilateral

Bilateral
Exoskeletons

Partial or Full Exoskeleton

Wire-based

Multi-robot
Representative Technologies
MIT-MANUS (2000)
Current commercial version InMotion ARM™

pronation/supination actuator

Velcro strap buckle
curve slide rings
Velcro strap buckle
flexion/extension and abduction/adduction actuator
differential and gear housing

handle connection
flexion/extension and abduction/adduction actuator
slider
MIME – Mirror-image Motion Enabler (2000)

- 6-DOF device
- Apply assistive or resistant forces to the paretic arm
- Bimanual mode
  - Assist patient to the paretic arm to mirror the healthy arm
ARM-Guide (2001)  
Assisted Rehabilitation and Measurement Guide

- 4-DOF device

- Allow patient wrist to reach along a linear track
T-WREX
Therapy Wilmington Robotic Exoskeleton

• 5-DOF device

• Allow patient to exercise in a more functional way
NeReBot (2005)
Neuro-Rehabilitation Robot

- 3-DOF device
- Cable-driven system
7-DOF Exoskeletons

SUEFUL-7 (2006)

UL7 (2007)
Trend in Device Design

• Hardware
  • From proximal to distal segments of upper limb
  • Standalone wrist and/or hand devices
  • Whole-limb device

• 2D to 3D motion

• Motor-based to function-based exercise
Therapy development

• Increase patient’s engagement
  • Assist-as-needed
  • Detection of patient intent to move
  • Virtual reality games for a more immersive experience
Assist as needed

- Impedance controller
- Controller algorithms
  - Specify a desired path
  - Desired path + desired completion time
    - How to define a desired trajectory?
  - Allowing subjects to choose their own
Limitation of “assist-as-needed” protocol

• Slacking

• How to fix?
  • Adjust the amount of robot’s support
  • Adjust task difficulties
Adjust robot’s support effort

- Include a forgetting term

- How to determine the appropriate amount of support?
  - Various modeling and estimation methods
Model and estimate task effort

- Dynamics of robot and patient’s arm
  - For full compensation

- Patient’s effort contribution
  - At various points of the workspace – Radial basis functions (RBFs)
  - Bayesian learning

- Patient’s effort with motion directionality
  - Flexion is harder than extension, or vise versa
Adjust task difficulty

- Increase required motion range after each successful trial
- Adjust task difficulty using machine learning methods
  - Based on the subject’s level of stress
  - Physiological measures – pulse rate, respiration rate, skin temperature, and galvanic skin response
Detection of Patient Intent

• Trigger robot assistance based on
  • Force, velocity, time thresholds ...
  • EMG, EEG

• Particularly for severely impaired patients who have trouble completing movements
Detect Motion Intent Using Force

With assistance

Without assistance
Detect Motion Intent Using EMG
Detect Motion Intent Using EEG
Effectiveness?

• Comparable to **equivalent intensive** training without robotic aid or an **equal number** of unassisted movements

• **Robotic therapy vs Conventional therapy?** → No significant difference

• **Robotic therapy + Conventional therapy?** → better, because of extra training duration/intensity


Assignment 05 – FK and IK for EXO UL 7

• Derive the FK and IK for UL 7
  • Resolve the arm kinematic redundancy by maximizing motion efficiency
  • Implement Matlab functions

• Reference
  • Zhi Li, Hyunchul Kim, Dejan Milutinovic and Jacob Rosen, “Synthesizing Redundancy Resolution Criteria of the Human Arm Posture in Reaching Movements”, In Redundancy in Robot Manipulators and Multi-robot systems (pp. 201-240). Springer Berlin Heidelberg, 2013
Limitations of Robot-assisted Rehabilitation

- Most robotic devices can only practice planner motion
  - Exercise shoulder and elbow, but not wrist

- Motor-based rather than function based

- “Assist as needed protocol” may reduce active engagement
  - Encourage patients to wait until the robot does the work for them