Upper Limb Exoskeletons for Stroke Rehabilitation

Jane Li

Assistant Professor
Mechanical Engineering Department, Robotic Engineering Program
Worcester Polytechnic Institute
Quiz (10 pts)

• Explain the clustering of coefficients in Criterion Contribution Inference
  • Be clear about how to determine the number of clusters
Criterion Contribution Inference

\[ \phi(k) = \sum_{i=1}^{5} c_i(k) \phi_i(k) \]

\( N_{\text{threshold}} = 9 \)

Sum of squared distance (%)

N of clusters

Clustering threshold.

Cluster distribution, \( N = 9 \).
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

- **Spontaneous neurological recovery**
- **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
Representative Technologies
MIT-MANUS (2000)

Current commercial version InMotion ARM™
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
  • Modeling efforts 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

Reach distance [mm]

Time [s]
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
Reference

• [1] Stroke Statistics from centers of disease control and prevention (CDC) for Year 2017


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