Lecture 15:
Rehabilitation
(movement therapy) robots

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some of this material is courtesy Machiel van der Loos
U.S. Demographics of Potential Therapy Robot Users

• Stroke:
  • 800,000 cases per year (incidence)

• Cerebral palsy:
  • 300,000 - 500,000 prevalence
  • 8,000 incidence

• Orthopedic interventions:
  • Post knee & hip replacement exercise
  • Ankle surgery
  • Trauma
Stroke Rehabilitation Strategies

• Important variables in optimal rehabilitation
  • Quantity
  • Duration
  • Intensity/repetition
  • Task-specific

• Robotic control strategies
  • Assisting movement
  • Challenging movement
  • Simulating normal tasks
  • Non-contact coaching


Research Phases in Robot-Assisted Stroke Therapy

1. Replicating the therapist
2. Augmenting the therapist
3. Designing the super-therapist
4. Enabling the inner therapist

H.F. Machiel Van der Loos (UCB)
Phase 1:
Replicating the therapist
MIME: Mirror-Image Movement Enabler (PA VA/Stanford)

Robotic system assisting upper limb neuro-rehabilitation

Facilitates paretic elbow and shoulder movement

Four modes of exercise:

- Passive
- Active-Assisted
- Active-Resisted
- Bimanual


MIT-MANUS, now InMotion (MIT)

Statistically significant improvement in Fugl-Meyer and clinical strength scales after 4-week regimen of daily 1-hour sessions.


ARM Guide (Rehab Institute of Chicago)

Linear slide with motor
6-dof force sensing

Phase 2: Augmenting the therapist
Driver’s SEAT
(PA VA/Stanford)
An upper limb one-degree-of-freedom robotic therapy device that incorporates a modified PC-based driving simulator.
Split Steering Wheel


Phase 3: Designing the super-therapist
Adding, then Removing Force-Field

A 315° trajectory from one stroke subject. (a) unperturbed baseline, (b) late machine learning, (c) early training, (d) late training, (e) aftereffects, (f) early washout, and (g) late washout. Desired trajectories are bold dotted lines, average trajectories are bold solid lines, individual trajectories are thin lines, and shaded areas indicate running 95% confidence intervals of ensemble.

‘Paris’ VR System (Rehab Institute of Chicago)

Goal: Better transfer to Activities of Daily Living

- 5-axis WAM manipulator
- Full-arm movement
- Projection of objects through glass
- Virtual object manipulation

http://www.smpp.northwestern.edu/robotLab/
Phase 4: Enabling the inner therapist
Using affect to change robot behavior


Lower-Extremity Rehabilitation Robots
PAM + ARTHUR walking aid

- Treadmill-based
- Pelvis assist (PAM) + walking assist (ARTHUR)
- PAM: linear actuators to support pelvis
- Linear actuators on rail to provide foot motion assist

http://www.eng.uci.edu/~dreinken/Biolab/biolab.htm
Lokomat Treadmill Walker

- Each side = 2 dof
- Linear actuators
- Supported treadmill walking
- Patients with stroke, iSCI

http://www.research-projects.unizh.ch/med/unit43000/area198/p1237.htm
UBC-CARIS Lab Balance Training


Robots for Neuroscience
Predicting and Correcting Ataxia Using a Model of Cerebellar Function and an Exoskeleton Robot

In collaboration with Nasir Bhanpuri and Amy Bastian
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Aim of rehabilitation robotics

and...
Transfer to activities of daily living
At-home rehabilitation or orthotics
Want learning or correction, not strategies

We need models of patient deficits!
Motion Incoordination: Cerebellar Ataxia

Control (Healthy)  Cerebellar
Exoskeleton robot

Control Subject

Cerebellar Subject

Hand Position

Hand Position

Hand Position

Hand Position

Shoulder Angle

Elbow Angle

Shoulder Torque

Elbow Torque

Time (normalized)

Time (normalized)
Single-jointed reaching: Arm flexion
control perturbations

model

Allison Okamura, Stanford University
Internal model inertia bias determined by the computational model is highly correlated with dysmetria.

\[
l_y = l_r - l_y
\]

\[
R = 0.887, \quad P = 0.0006
\]

\[
y = 0.035x - 0.034
\]

Graph showing correlation between dysmetria and inertia bias with different symbols representing different conditions.

- Spinocerebellar Ataxia
- Sporadic Ataxia
- Autosomal Dominant Cerebellar Ataxia
- Multiple System Atrophy
Implement compensation

\[ \text{force} = \text{mass} \times \text{acceleration} \]

Here, mass can be positive or negative!
Results of robot intervention

If a patient has **hypermetria**, use the robot to **decrease** their inertia

If a patient has **hypometria**, use the robot to **increase** their inertia

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**Individuals**

**Group**

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**Individuals**

**Group**
We find **patient-specific** biases in dynamics representation.

We can **replicate dysmetria** by creating a mismatch in dynamics (inertia) in healthy people and using simulation.

We can partially **correct dysmetria** by altering patient limb inertia with a robot. This does not correct trial-to-trial variability.