Pediatric Robotics – A Journey from the Lab to a Child’s Home

Session #56, February 12, 2019

Ayanna Howard, Professor, Georgia Tech
Don Woodlock, Vice President, Intersystems Corporation
Agenda

• Problem Statement
• Overview of Healthcare Robotics
• Motivation for Pediatric Robotics
• Presentation of the Pediatric Robotic System
• Results from Pre-Clinical Studies
• Concluding Remarks
• Q&A
Learning Objectives

• Discuss the role of robotics and related technologies for pediatric therapy
• Illustrate challenges to enable successful interaction between patients, clinicians, and robots
• Describe technologies to address real-life therapy goals for children with special needs
• Evaluate methods for improving the rehabilitation outcomes of children
• Discuss artificial intelligence methods to endow robots with the ability to playfully interact with the child
About Disabilities

Disability ... the state of being limited, due to a chronic mental or physical health condition, in the type or amount of normative activities that a person is expected to perform.

In countries with life expectancies > 70 years of age, individuals will spend ~8 years of their life span, living with a disability.
150 MILLION CHILDREN WITH DISABILITIES WORLDWIDE

$1.6 BILLION U.S. PEDIATRIC REHABILITATION INDUSTRY

15% of the world’s population live with a disability
Robots to Enable Us

1965: GE Hardiman

ReWalk - http://rewalk.com, today
Robots to Augment Us

1867: Samuel Decker
https://twentytwowords.com/civil-war-veterans-ingenious-self-designed-mechanical-arms-3-pictures/

DEKA, Rehabilitation Institute of Chicago
Robots Controlled by Us

University of Pittsburgh, 2012

University of Pittsburgh, 2008
Why Robots for Pediatrics?

• Most children, including children with disabilities, are attracted to robots.

• This natural affinity can be exploited, and the robot used as an interactive motivator through repetitive and predictable interaction.
Statistics of changes in Autism Spectrum Disorder (ASD) occurrence over the past three decades (USA)
Physiotherapy Sessions

Challenge: Child Movement Behavior

- Wide variation of movement profiles in children with movement disorders
- Classify gross motor function using the Gross Motor Functional Classification System (GMFCS)

GMFCS II

GMFCS IV
Challenge: Child Cognitive Behavior

- With repetitive or monotonous conditions over time, performance decreases due to reduced arousal (Cooley and Morris, 1990)

- Generally, sustained attention improves with age

From Child-Clinician to Child-Robot Interaction
Robot-Assisted Therapy System

Gamified Therapy

Assistive Technology

Robot Therapy Coach
Robot-Assisted Therapy System

Gamified Therapy

Assistive Technology

Robot Therapy Coach
Virtual Reality Therapy Game
Tablet-Based Therapy Games

- Many clinicians use cause-and-effect mobile apps since this concept is an important step in a child’s developmental process.
- Purposeful movement across space will not occur until a child with special needs understands this concept of cause-and-effect.
Robot-Assisted Therapy System

Gamified Therapy

Assistive Technology

Robot Therapy Coach
The First Input (AT) Device
Expanding Market Size (The Pivot)

• Needed device to engage younger children
• Needed a larger customer base to reduce production costs
Physical Therapy Metrics

• To provide feedback to the clinician, need to quantify rehabilitation measures

• Peabody Developmental Motor Scales – used to assess gross and fine motor skills

• Kinematic Parameters:
  – Range of Motion
  – Deviation from Path
  – Path Length
  – Movement Time
  – Movement Smoothness
  – Average Movement Speed
Quantifying Movements

Accuracy wrt ground truth: ROM ∈ [5, 7]%   Path Length ∈ [10.5, 12.5]%
Importance of Baselines

c. o. Butler et al. 2010
Kinematic Model

• Require a baseline for comparing measures with respect to a norm. We construct a 4 DOF model that mimics the kinematics of the human arm.

• Generates an optimal path between two points in space as a function of:
  – User’s arm’s link lengths.
  – User’s arm’s initial pose.
  – Position of the target.

• Resulting trajectory is a curve that matches the structure of the curve generated by an individual’s movements. [Morasso et al. 1981]
Baseline Validation

Elbow Range of Motion (EROM), Shoulder Range of Motion (SROM), Deviation from Path (DfL): *Are the two baselines equivalent?*

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Right Arm</th>
<th>Left Arm</th>
</tr>
</thead>
<tbody>
<tr>
<td>DfL $[10^{-3} m^2]$</td>
<td>27.86</td>
<td>35.60</td>
</tr>
<tr>
<td>EROM $[\text{deg}]$</td>
<td>4.25</td>
<td>5.48</td>
</tr>
<tr>
<td>SROM $[\text{deg}]$</td>
<td>27.57</td>
<td>29.66</td>
</tr>
<tr>
<td>PL $[\text{mm}]$</td>
<td>346.84</td>
<td>398.18</td>
</tr>
</tbody>
</table>

**Means [Human Model]:**
- DfL: 27.86
- EROM: 4.25
- SROM: 27.57
- PL: 346.84

**Means [Kinematic Model]:**
- DfL: 32.03
- EROM: 5.59
- SROM: 29.03
- PL: 289.83

**99.99% CI Bounds $[\pm]$**
- DfL: ±9.62
- EROM: ±2.36
- SROM: ±4.02
- PL: ±42.63

**Participant Pool:** Able-bodied Adults

**No. of Participants:** 10 {6 females | 4 males}

**Age Range [years]:** 24-31

**General Description:** Participants completed a 90° trajectory 10 times for each arm.

**Effect Sizes ~ 0**

**CI Bounds:**
- $< 5^\circ$ for EROM and SROM parameters.
- $\in [1, 15] \times 10^{-3} m^2$ for DfL parameter.
Children with Typical Development

Bent elbow

Popped with “wrong” hand
Baseline Validation

Typical baseline models created by collecting human data shows an error ranging from 13.8% to 66.7%.

<table>
<thead>
<tr>
<th>Participants</th>
<th>Elbow ROM [deg]</th>
<th>Error [%]</th>
<th>Shoulder ROM [deg]</th>
<th>Error [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>27.45</td>
<td>10.74</td>
<td>46.27</td>
<td>17.59</td>
</tr>
<tr>
<td>2</td>
<td>27.65</td>
<td>12.45</td>
<td>34.16</td>
<td>12.20</td>
</tr>
<tr>
<td>3</td>
<td>7.38</td>
<td>4.42</td>
<td>31.58</td>
<td>2.46</td>
</tr>
<tr>
<td>4</td>
<td>6.62</td>
<td>2.10</td>
<td>25.84</td>
<td>2.12</td>
</tr>
<tr>
<td>5</td>
<td>27.38</td>
<td>17.88</td>
<td>20.09</td>
<td>9.15</td>
</tr>
<tr>
<td>6</td>
<td>0.23</td>
<td>4.38</td>
<td>19.31</td>
<td>3.18</td>
</tr>
<tr>
<td>7</td>
<td>16.93</td>
<td>3.01</td>
<td>36.28</td>
<td>1.22</td>
</tr>
<tr>
<td>8</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>9</td>
<td>2.92</td>
<td>2.63</td>
<td>21.73</td>
<td>0.99</td>
</tr>
<tr>
<td>10</td>
<td>3.27</td>
<td>1.63</td>
<td>17.11</td>
<td>2.68</td>
</tr>
<tr>
<td>11</td>
<td>5.06</td>
<td>1.71</td>
<td>47.63</td>
<td>2.93</td>
</tr>
<tr>
<td>AVG</td>
<td>6.10</td>
<td></td>
<td>5.45</td>
<td></td>
</tr>
<tr>
<td>STD</td>
<td>5.32</td>
<td></td>
<td>5.33</td>
<td></td>
</tr>
</tbody>
</table>

*Missing values are due to corrupt data in the collection process.

Participant Pool

<table>
<thead>
<tr>
<th>Typically Developing Children</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of Participants</td>
</tr>
<tr>
<td>Age Range [years]</td>
</tr>
</tbody>
</table>
# Pre-Clinical Trials I: Feasibility

<table>
<thead>
<tr>
<th>Participant Pool</th>
<th>Children with Cerebral Palsy</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of Participants</td>
<td>3 {3 females | 0 males}</td>
</tr>
<tr>
<td>Age Range [years]</td>
<td>9 ± 1.73</td>
</tr>
<tr>
<td>General Description</td>
<td>Received a 8-week VR intervention and were asked to maintain their regular physical therapy sessions.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Participant Pool</th>
<th>Typically Developing Children</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of Participants</td>
<td>11 {6 females | 5 males}</td>
</tr>
<tr>
<td>Age Range [years]</td>
<td>8.87 ± 1.87</td>
</tr>
<tr>
<td>General Description</td>
<td>Played once and their outcome measures served as the ‘norm’ comparison.</td>
</tr>
</tbody>
</table>
# Pre-Clinical Trials I: Feasibility

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-test</td>
<td>0.93</td>
<td>2.34</td>
<td>4.83</td>
<td>0.52</td>
<td>21.37</td>
<td>48.73</td>
</tr>
<tr>
<td>Mid-test</td>
<td>0.52</td>
<td>1.17</td>
<td>4.23</td>
<td>0.46</td>
<td>18.23</td>
<td>37.14</td>
</tr>
<tr>
<td>Post-test</td>
<td>0.42</td>
<td>0.97</td>
<td>2.52</td>
<td>0.82</td>
<td>17.93</td>
<td>24.31</td>
</tr>
<tr>
<td>TD Children [AVG]</td>
<td>0.43</td>
<td>0.80</td>
<td>2.23</td>
<td>0.61</td>
<td>16.25</td>
<td>35.49</td>
</tr>
<tr>
<td>TD Children [STD]</td>
<td>0.17</td>
<td>0.26</td>
<td>1.06</td>
<td>0.24</td>
<td>8.88</td>
<td>9.79</td>
</tr>
</tbody>
</table>

**PL**: Path Length  
**MT**: Movement Time  
**MUs**: Movement Units  
**AvgS**: Average Hand Speed  
**EROM**: Elbow Range of Motion  
**SROM**: Shoulder Range of Motion

<table>
<thead>
<tr>
<th>Kinematic Parameters</th>
<th>PL</th>
<th>MT</th>
<th>MUs</th>
<th>AvgS</th>
<th>EROM</th>
<th>SROM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-test</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Mid-test</td>
<td>x</td>
<td>✓</td>
<td>✓</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Post-test</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
</tbody>
</table>

✓: there is a statistical difference between the group of children with CP and without  
✗: there is no statistically significant difference
Pre-Clinical Trials I: Feasibility

Our games provide a feasible method for use with children with movement disorders to collect desired reaching kinematics in their natural environment.

How do we incorporate the robot playmate for enhancing the feedback and motivation?
Interactive Robot Play Strategies
Robot Coach: Engagement Strategies
Mimicking Physiotherapy Sessions
“Move faster, bend elbow, reach object, stand up, not like that, move your shoulder 35.5 degrees, etc…”

“Move and wait 30 minutes…”

<table>
<thead>
<tr>
<th>Movement Time, $MT$</th>
<th>Verbal</th>
<th>Nonverbal</th>
</tr>
</thead>
<tbody>
<tr>
<td>$MT &gt; target$</td>
<td>“Great job. Move a little faster like this…”</td>
<td>![Nonverbal icon]</td>
</tr>
<tr>
<td>$MT &lt; target$</td>
<td>“Great job. Move a little slower like this…”</td>
<td></td>
</tr>
<tr>
<td>$MT = target$</td>
<td>“Fantastic.”</td>
<td></td>
</tr>
</tbody>
</table>
Pilot Study: Guiding Performance through Feedback

Phase 1

Phase 2 (H₁)

>> TH = 0.8*avg.P1 = 2.7900

Phase 3 (H₂)

>> MTs.P3 =
3.7872
2.2598
2.2895
3.3632
2.6043
2.4635
2.2424
2.2807
2.1325
2.3900
...
>> avg.P3 =
2.9849

"Move a little faster."
But, there’s a Little Problem

Humans are Trusting
Trust Assessment

Children
10 {3 females | 7 males}
Mean Age: 5.93

Trust Assessment

Adults
20 {11 females | 9 males}
17 to 26 years old

“\text{I trusted the robot/therapist when I made my choice to follow guidance or not follow guidance from the robot.}”

<table>
<thead>
<tr>
<th>% choose to follow guidance from the therapist</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Robot</td>
<td>80%</td>
<td>20%</td>
</tr>
<tr>
<td>Human</td>
<td>90%</td>
<td>10%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>% trusted the therapist when decision was made</th>
<th>Agree</th>
<th>Disagree</th>
<th>Not involved</th>
</tr>
</thead>
<tbody>
<tr>
<td>Robot</td>
<td>60%</td>
<td>10%</td>
<td>30%</td>
</tr>
<tr>
<td>Human</td>
<td>40%</td>
<td>0%</td>
<td>60%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>% willing to follow the therapist’s guidance next time</th>
<th>Agree</th>
<th>Disagree</th>
<th>Not involved</th>
</tr>
</thead>
<tbody>
<tr>
<td>Robot</td>
<td>70%</td>
<td>10%</td>
<td>20%</td>
</tr>
<tr>
<td>Human</td>
<td>80%</td>
<td>10%</td>
<td>10%</td>
</tr>
</tbody>
</table>

Therapist condition has a medium-sized effect ($r = 0.35$) on trust in participants
Next Steps ...

- As pediatric robotics becomes more advanced, how far can we push it? How far **should** we push it?
Robots and Children can Play Together
Ask questions. Hear experts discuss the major issues impacting computing and the world.

Available on iTunes and Spotify – search “The Interaction Hour”

Remember to complete online session evaluation