State of the Art of Wearable Robotics and Major Advances

Parent Project Muscular Dystrophy’s 2017 Connect Conference
07/02/2017
Hao Su, PhD, Assistant Professor
City University of New York, NY, NY
Outline

• Background
• Wearable Robots for Lower Limbs: Mobility
• Wearable Robots for Upper Limbs: Manipulability
• Research at CUNY: Low-cost, Modular, Smart
• Future Directions
Hao Su, PhD

- **Work Experiences**
  - Assistant Professor, Mechanical Engineering, City University of New York
  - 2015-2017 Postdoc, Harvard University
  - 2013-2015 Research Scientist, Philips Research North America

- **Education**
  - Ph.D., Mechanical Engineering, Worcester Polytechnic Institute

- **Awards**
  - Philips Innovation Transfer Award
  - Best Medical Robotics Paper Runner-up, International Conference on Robotics & Automation
  - Link Foundation Fellowship in Advanced Simulation and Training (1 of 2 recipients in N.A.)

- **Professional Services**
  - Associate editor: International Conference on Robotics & Automation (ICRA),
  - Associate editor: Engineering in Medicine and Biology Society (EMBC)
  - Junior Chair, Technical Committee on Mechanisms and Design
    IEEE Robotics and Automation Society (RAS)
Co-Robots in the Continuum of Care

**Background**

- MRI-compatible surgical robots
  - Fiber Optic Sensors
  - Piezoelectric Motors
  - Concentric Tube Steerable Robots

- Soft wearable robots
  - High Torque Actuators
  - Wearable Sensors
  - Soft Actuators, Haptics

*Concentric tube robot credit: collaborator Robert Webster
Jimmy robot is Tianyao Chen’s work at Disney*
Tianyao Chen, PhD

- M.S., Carnegie Mellon University
- PhD, Catholic University of America
- Best Medical Robotics Paper
  IEEE International Conference on Robotics and Automation

### Background

Wearable Robots for Lower Limbs
Therapeutic vs. Personal Mobility Device

Full-body

Single joint

Cyberdyne
Indego
Harvard ankle/hip
Keeogo knee

Rewalk
Ekso Bionics
Honda hip
CMU ankle
Wearable Robots for Lower Limbs

- 😊 Great tool for early mobilization
- 😞 Restrict natural human movement
- 😞 Increase metabolic cost
- 😞 Too expensive
- 😞 Not personal mobility devices
- 😞 Typically heavy, bulky

Chris Tagatac
## Wearable Robots for Upper Limbs

<table>
<thead>
<tr>
<th>Institutes</th>
<th>ARMIN III</th>
<th>Manus</th>
<th>Limpact</th>
<th>Soft Arm</th>
</tr>
</thead>
<tbody>
<tr>
<td>ETH, Switzerland</td>
<td>MIT</td>
<td>Netherlands</td>
<td>Catholic U of America</td>
<td></td>
</tr>
<tr>
<td>Features</td>
<td>Wearable</td>
<td>End-effector</td>
<td>Hydraulic</td>
<td>Low impedance</td>
</tr>
<tr>
<td>Mass</td>
<td>18kg</td>
<td>6kg</td>
<td>8kg</td>
<td>1.4kg</td>
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<tr>
<td>DOF</td>
<td>5</td>
<td>2</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Cost</td>
<td>$80,000</td>
<td>$60,000</td>
<td>NA</td>
<td>&lt;$20,000</td>
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</table>

#PPMDCConnect  Lower Limb Robots  Parent Project Muscular Dystrophy
Wearable Robots for Upper Limbs

Flextension

Innovator:
Arjen Bergsma & Micha Paalman

Community Member:
Justus Kuijer

PPMD conducted community survey of preferences related to robotics in 2015

Clear priorities among the highly valued activities include:
- standing from a seated position
- picking up on object from the floor
- repositioning oneself at night, and
- the ability to bring one’s hands to mouth

Slides: Pat Furlong
Wearable Robots for Upper Limbs

Solid Suit
Innovator: SRI

X-Ar Arm
Innovator: Blake Mathie
Community Member: Zach Smith

Slides: Pat Furlong

Human in the Loop
3D Printable Exoskeleton

Carbon fiber orthosis
- Risk of fall

Articulated orthosis
- Reduce compensations
- Reduced range of motion

3D Printable modular exo
- Diagnosis/prognosis
- Prescription
- Active assistance

Smart Wearable Robots in the Continuum of Care

**Diagnosis**
- Cadence
- Pelvis tilt
- Ankle angle

**Prescription**
- Timing
- Magnitude
- Profile

**Robotic orthosis**
- Ankle module
- Knee module
- Hip module

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Wearable sensor suit

Universal assistance emulator

Modular soft exoskeleton
Hip Exoskeleton Working Principle

## Modular Exoskeleton vs. Gait Disorders

<table>
<thead>
<tr>
<th>Module</th>
<th>Biomechanics</th>
<th>Gait disorder</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ankle plantarflexion</td>
<td>Propulsion stability</td>
<td>Toe-to-heel gait</td>
</tr>
<tr>
<td>Ankle dorsiflexion</td>
<td>Ground clearance</td>
<td>Foot drop, toe walking</td>
</tr>
<tr>
<td>Hip flexion</td>
<td>Ground clearance</td>
<td>• Anterior pelvic tilt&lt;br&gt;• Trendelenburg gait</td>
</tr>
<tr>
<td>Hip extension</td>
<td>Propulsion stability</td>
<td>Knee hyperextension</td>
</tr>
</tbody>
</table>
3D Printable Hip Exoskeleton

- Low cost: $2400 bilateral hip exoskeleton

[1] Ziqing Wang. School of Mechanical Engineering, Nanjing University of Science and Technology, Nanjing, China

Waist belt
Controller
Actuator
Thigh wrap
IMU sensor
3D Printable Hip Exoskeleton

- Multi-mode of operation

**Assistive mode**
1. Passive control
   - Passive trajectory tracking, Passive mirroring, Passive stretching
2. Triggered passive control
3. Partially assistive control
   - Impedance/Admittance control, Attractive force-field, Model-based assistance, Offline adaptive control

**Corrective mode**
1. Tunneling
2. Coordination control

**Resistive mode**
- no controls developed yet

*Orthosis + passive assistance + Motor module* -> *Active assistance*

# PPMDConnect  
CUNY Lower Limb Robots
3D Printable Upper Limb Exoskeleton

- Portable
- Low cost: $500
- 4 DOF
  - Shoulder: Abduction, adduction
  - Shoulder: Flexion, extension
  - Elbow: Flexion, extension
  - Elbow: Pronation, supination

Basic shoulder movements

#PPMDCConnect  CUNY Upper Limb Robots
3D Printable Upper Limb Exoskeleton

- Portable
- Low cost: $500
- 4 DOF
  - Shoulder: Abduction, adduction
  - Shoulder: Flexion, extension
  - Elbow: Flexion, extension
  - Elbow: Pronation, supination
Future Directions

• Now: exos for the clinic
• Future: across the continuum of care from inpatient to home mobility & wellness
• Lower limb wearable robots
  – Reduce the cost: 3D printable, chip level solution
  – Low impedance: non-disruptive to natural motion
• Upper limb exo wearable robots
  – Activities of daily living: end-effector vs. wearable device?
  – Control is the key
Ubiquitous Co-Robots: Human-Environment Interface

Martin Cooper, 1973

- Hao Su, PhD, Assistant Professor
- City University of New York
- Email: haosu.robotix@gmail.com

Future Directions