Wearable Technology and its Applications in Physical Medicine and Rehabilitation

Paolo Bonato, PhD

Department of Physical Medicine and Rehabilitation
Harvard Medical School, Spaulding Rehabilitation Hospital
&
The Harvard-MIT Division of Health Sciences and Technology
pbonato@partners.org
Disclosures

- My team contributed to the development of the Shimmer Sensor Platform and received funding from Intel to test the platform in patients with COPD – no other financial relationship with Intel and the company that licensed the technology from Intel (i.e. Shimmer Research).

- I serve as a member of Hocoma’s scientific advisory board (uncompensated position) and my team received in the past (2009) scholarship funds for graduate students working on the Lokomat system.
Outline

- **Motivation**
  Why we are interested in wearable technology.

- **Design Criteria**
  How we take on the design of wearable systems.

- **Stroke Rehabilitation**
  Body sensor networks can track motor recovery in stroke survivors.

- **Traumatic Brain Injury**
  E-textile monitoring of hand movements can improve upper extremity rehabilitation.

- **Older Adults**
  Improving fall detection by combining wearable technology and home robots.
Continuous Physiological Monitoring

The concept of continuous physiological monitoring has been around since 1949, when Norman Holter proposed to pursue electrocardiographic monitoring via a rather obtrusive but revolutionary system to record cardiac activity.
Patients with Mobility-Limiting Conditions

The focus of our research group is on developing techniques for the assessment of movement patterns in patients with mobility limiting conditions.

Our objective is to provide clinicians with tools to tailor clinical interventions on the basis of responses gathered from each patient and to facilitate rehabilitation interventions.
Field Monitoring via Wearable Systems

- ECG & Respiration
- Location (GPS) Communication Gateway
- Cell phone network
- Bluetooth/WLAN
- Internet
- Emergency
- Family/Caregiver
- Clinician

e-textile Data Glove

Motion Analysis Laboratory
Outline

- **Motivation**
  Why we are interested in wearable technology.

- **Design Criteria**
  How we take on the design of wearable systems.

- **Stroke Rehabilitation**
  Body sensor networks can track motor recovery in stroke survivors.

- **Traumatic Brain Injury**
  E-textile monitoring of hand movements can improve upper extremity rehabilitation.

- **Older Adults**
  Improving fall detection by combining wearable technology and home robots.
What Can We Do with Data Gathered Using Wearable Systems?

Identification of Motor Tasks

**Health Status in COPD Patients**

Working with our colleagues at Brigham and Women’s Hospital, we demonstrated that exercise conditions (e.g. cycling on a stationary bike) and ambulatory tasks (e.g. stair ambulation) can be identified with sensitivity > 80% and misclassification < 10%. Ambulatory tasks were chosen to monitor systemic responses associated with differently demanding tasks.
What Can We Do with Data Gathered Using Wearable Systems?

Assessment of Quality of Movement

Titrating Medications in Patients with PD

By analyzing accelerometer data recorded during the performance of UPDRS motor tasks, one can estimate the severity of symptoms and motor complications in patients with Parkinson’s disease. In the late stages of this condition, tracking fluctuations in the severity of Parkinsonian symptoms facilitates the titration of medications.
What Can We Do with Data Gathered Using Wearable Systems?

Enhancement of Mobility Devices

A Knee Brace for Gait Retraining

Our colleagues at Northeastern University and our team are developing the next generation of orthotic devices aimed at facilitating gait retraining in Subjects with hemiparesis (such as in traumatic brain injury survivors). These are robotic systems that are controlled using a closed-loop approach based on data from wearable sensors.
Defining “Functional” Specifications …

- How critical is the information to be gathered and relayed by the wearable system?

- How long will subjects wear the system and during performance of what type of motor activities?

- How quickly will it be necessary to relay the information gathered by the wearable system to a remote site?

- How critical will it be the integration of wearable sensor data with data collected using sensors and devices in the environment?
Outline

- **Motivation**
  Why we are interested in wearable technology.

- **Design Criteria**
  How we take on the design of wearable systems.

- **Stroke Rehabilitation**
  Body sensor networks can track motor recovery in stroke survivors.

- **Traumatic Brain Injury**
  E-textile monitoring of hand movements can improve upper extremity rehabilitation.

- **Older Adults**
  Improving fall detection by combining wearable technology and home robots.
Stroke

- Stroke is a major cause of disability
- >700,000 new cases in the United States annually
- >150,000 Americans die each year
- Only about 15% of those with initial complete upper limb paralysis recover its functional use
- Clinical assessments of motor performance serve a critical role in guiding rehabilitation after stroke.

From Shumway-Cook and Woollacott, Motor Control, Lippincott Williams & Wilkins 2001
Study Aims

- Identify functional tasks during continuous monitoring
- Decompose functional tasks into movement components
- Assess the quality of movement of patients based on analysis of sensor data from these movement components
- 24 subjects with residual upper limb weakness (hemiparesis) participated in a laboratory study of motor performance.
Monitoring Stroke Survivors

- **Goal**: Assessing quality of movement in the home setting.

- **Intervention**: home-based motor training program.

- **Clinical Requirements**: tracking response to rehabilitation interventions
  - sample data for several hours every few days for the period of intervention
  - spot checks “low resolution” data
  - gather information from subjects

- **Technical Solutions**: nodes equipped with inertial sensors
  - web-based application
  - estimation of data features on the nodes
  - development of algorithms
  - annotation tools
Experimental Setup
Data Segmentation

Lifting a Soda Can

Time (s)

Thumb Acceleration (g)

Hand X Acceleration (g)

Forearm Y Acceleration (g)

S1
S2
S3

0 1 2 3 4 5 6
# Motor Tasks

<table>
<thead>
<tr>
<th>Tasks</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Reaching</strong></td>
<td></td>
</tr>
<tr>
<td>FAS 1</td>
<td>Placing forearm on the table</td>
</tr>
<tr>
<td>FAS 4</td>
<td>Extending elbow to the side with a weight</td>
</tr>
<tr>
<td>FAS 5</td>
<td>Placing hand on the table</td>
</tr>
<tr>
<td>FAS 8</td>
<td>Retrieving a weight by flexing the elbow</td>
</tr>
<tr>
<td><strong>Manipulation</strong></td>
<td></td>
</tr>
<tr>
<td>FAS 9</td>
<td>Lifting a soda can</td>
</tr>
<tr>
<td>FAS 10</td>
<td>Lifting a pencil</td>
</tr>
<tr>
<td>FAS 13</td>
<td>Flipping an index card</td>
</tr>
<tr>
<td>FAS 15</td>
<td>Turning key in a lock</td>
</tr>
</tbody>
</table>
Estimating Total FAS Score

Linear Fit: \( Y = (0.97)X + 3.1 \)

\( R^2 = 0.961125 \)

Data Points
Best Linear Fit
\( Y = X \)
Remote Access to Wearable Sensor Data
Remote Access to Wearable Sensor Data

- Reading **external sensors data**
- Wireless communication
  - Start/Stop/Query **commands**
- Data storage: **SD Card**
  - Reading utilities ready
- **Energy monitoring** (only on Shimmer 2r)

- Wireless communication
  - **Manage sensor remotely**
- **Data management**:
  - Plot of data
  - Storage on the phone
- **Automatic sensor recognition**
Toward Deployment in the Home

- The technique we have developed has the potential for allowing us to monitor stroke survivors in the home setting.
- Ideally, monitoring technology would be deployed while implementing home-based rehabilitation interventions.
- Robotics (particularly low-cost systems) has gained the attention of therapists as a means to achieve high-intensity interventions.
Outline

- **Motivation**
  Why we are interested in wearable technology.

- **Design Criteria**
  How we take on the design of wearable systems.

- **Stroke Rehabilitation**
  Body sensor networks can track motor recovery in stroke survivors.

- **Traumatic Brain Injury**
  E-textile monitoring of hand movements can improve upper extremity rehabilitation.

- **Older Adults**
  Improving fall detection by combining wearable technology and home robots.
Recent reviews of the literature (e.g. Kwakkel et al, Neurorehabilitation and Neural Repair, 22(2): 111-121, 2008; Mehrholz et al, Cochrane Database of Systematic Reviews, 4, CD006876, 2008) suggest that individuals post stroke improve arm motor function and strength of the paretic arm following robot-assisted arm training. However, studies show a limited impact on the ability of patients to perform activities of daily living.
Single Sensor Characterization

While tracking movements of flexion/extension of the index finger using a camera-based system, we recoded the output of sensors positioned across the joint of interest.
Combining the Glove with a Robotic System

The sensorized glove replaces the grip sensor in the ARMEO thus providing an opportunity for training grasp and release function with actual extension of the hand/fingers.
Outline

- **Motivation**
  Why we are interested in wearable technology.

- **Design Criteria**
  How we take on the design of wearable systems.

- **Stroke Rehabilitation**
  Body sensor networks can track motor recovery in stroke survivors.

- **Traumatic Brain Injury**
  E-textile monitoring of hand movements can improve upper extremity rehabilitation.

- **Older Adults**
  Improving fall detection by combining wearable technology and home robots.
Partners Healthcare is currently using Philips Lifeline to detect falls in older adults. Does it work? … Unfortunately, this type of system is marked by low compliance …
A Solution to Improve Fall Detection

A potential improvement in fall detection and the prevention of injuries could be achieved by combining wearable sensor technology and robotics.

Wearable sensors (and sensors in the home environment) could be set to detect falls with high sensitivity and … the robot could take care of the false alarms.

Besides, the robot could detect falls (with less accuracy) even when the subject does not wear any sensors …
A Solution to Improve Fall Detection
Take Home Message …

There are numerous potential applications of wearable technology in rehabilitation …

The “low-hanging” fruit is in applications where we focus on combining existing technologies to improve rehabilitation interventions.

The long-term opportunity is in developing new systems to monitor upper and lower extremity functions and facilitate functional improvements via home-based motor training interventions.

The challenge is in making such systems “deployable” in the large scale … which requires striking a balance between costs and benefits.
Acknowledgments

Sponsors
National Institutes of Health, National Science Foundation, CIMIT (DoD/TATRC), Hocoma, Intel

Motion Analysis Lab Current and Former Members
Chek-Wai Bok, Effie Chew, Fausto Crapanzano, Silvia Del Din, Luca Della Toffola, Marco Di Gesu`, Todd Hester, Richard Hughes, Chiara Mancinelli, Yalgin Muzaffer, Shyamal Patel, Ben Patritti, Fernanda Romaguera, Sofia Straudi

Collaborators
Questions?
Paolo Bonato, PhD
Director, Motion Analysis Laboratory
Dept of Physical Medicine and Rehabilitation
Harvard Medical School
at Spaulding Rehabilitation Hospital
125 Nashua Street
Boston MA 02114

Phone # 617-573-2745
Fax # 617-573-2769
Email pbonato@partners.org