Personal Measurement of Physical Activity

(Using mobile phones and Wockey)

Northeastern/MIT/Stanford Medical

Stephen Intille*, Fahd Albinali (EveryFit), Selene Mota (MIT), Benjamin Kuris (Shimmer Research), Pilar Botana (MIT), William Haskell (Stanford Medical)

*Associate Professor
  College of Computer and Information Science & Bouvé College of Health Sciences
  Northeastern University
  Boston, Massachusetts
  s.intille@neu.edu
Motivation

- **NIH Genes and Environment Initiative (GEI)**
  - Understand genetic and environmental contributions to health and disease

- **Exposure Biology**: Tools for measuring exposure in large cohort studies
  (Physical activity, diet, psychosocial stress and addictive substances, chemicals)
Physical activity measurement

• Develop new or refine existing technologies to measure PA
  – Reliable and valid
  – Low respondent burden
  – Economically feasible for use in large studies of free-living, diverse populations

• “Small-scale” validation
Wockets system

• Goal
  – 24/7 measurement of physical activity of
    • Type
    • Intensity
    • Duration
    • Location
  – For months+ (with compliance feedback)
  – Cost suitable for cohort studies
    • Exploit consumer phone technologies
    • All open source
Vision: population-scale

App Store

Participant has flexibility in how to wear/use sensors

New surveys/interventions remotely loaded & administered; remote software updates w/ new capabilities

24/7 Real-time PA detection and context-sensitive self report with sensors (GPS, phone)

Data sent to server for analysis & remote administration

Real-time feedback to encourage compliance

Years
Activity monitors abound
Personal Measurement of Physical Activity

+ Measurement on phones

StepLively
An app designed to help you walk more everyday

You get points for your movement

= Points

You get stars as rewards for outperforming old records.

last monda
Why yet another monitor?

- Cost (exploit phones, minimize hardware)
- Data: summary and raw data
- Participant burden: Wearable 24/7 with minimal burden, including during sleep
- Multiple locations (upper/lower body)
- Real-time feedback for compliance
- Remote administration of long-term studies with data validation
Wockets system fills a niche

- 24/7 remote data collection that may improve PA/SB research
  - Missing data
    - Real-time compliance feedback
    - Remote compliance monitoring
    - Less reliance on single body location
  - Sampling bias
  - Activity type info via pattern recognition with upper/lower body sensing
Participatory design

20 people: ages 22-82, many with busy schedules (farmer, midwife, executive director), representing diverse lifestyles (single parents, retired persons). Most use technology “as needed” -- not early adopters.
System requirements

• 3-axis, 40Hz, raw accelerometer data
• Multiple sensors in real-time
• Optimized for size
• Optimized for affordability/exploit phone
  (and can assemble in small and large quantities)
• Worn comfortably under clothing for months (thin, unobtrusive)
• Single swap/day “habit”
• Robust
Wocket “kit” (+ phone)

Charge 2

Wear 2 for 24h

Capture upper + lower body motion at 40Hz that can be processed for activity type and intensity detection
Thin for continuous wearability

Actigraph

Wocket
Usability critical

WRIST AND ANKLE BAND DESIGN

POCKET BAG DESIGN
Current phones

• Windows Mobile 6.5
• Android (in final testing)
Continuous data collection

- 2 sensors wearing, 2 charging
- Summary data sent hourly to server
- Plug phone nightly (uploads raw data)
- Wockets last 42+ hours, phone waking day
- Phone detects data quality & missingness in real time and provides feedback to encourage study compliance
Note: Activities manually labeled ...

Working on real-time detection of some activity types and context (posture, ambulation, structure exercise, etc.)
Wed morning

- Hitting snooze
- Sleep
- Shower (sensors off)
- Walk dog
- Driving and walking, doing small errands
- Climb stairs
- In meeting
- Stairs then walk across campus
- In meeting
- Walking then stairs
- In meeting
- Stairs then walking briskly
- Brisk to trä
Posture shifts during sleep

Evening

Thu night

Fri m
You are viewing data for Thursday 21st of July 2011

Participants:
Intille, Stephen

View By:
Placement, MAC Address

Show Options:
Raw Data, Bytes Sent, Bytes Received, Battery, Phone Stats

SMS #2131
On Wednesday we recorded 99.7% of the data from your wrist sensor and 99.2% of the data from your ankle sensor.

SMS #2137
On Wednesday according to your ankle sensor: Sedentary 18 hours, Light activity 4 hours, Physically active 115 minutes.
41.7h+ continuous logging

• Two modes:
  – Continuous (about 8 hours on a phone)
  – Burst (send raw data 1/minute)

• Limiting battery factor is phone, not Wocket

• Goal: 24 hours under normal use
42 hours on one extended battery charge
A day in the life of a participant

• In the morning, swap & select locations
• During the day
  – Standard Battery (1100-1400 mAh)
    • Remaining charge for other activities on phone: 30%-45%
  – Extended Battery (2200 mAh)
    • Remaining charge for other activities on phone: 65%
• At night, plug in phone next to bed
• Data transmitted to lab for remote monitoring
Controlled data collection with Stanford collaborators

- Oxycon mask
- Oxycon harness
- Polar strap
- Zephyr bioharness
- Multiple wireless accelerometers
- Actigraph
- Omron
### Lab performance: Activity rec

<table>
<thead>
<tr>
<th>Activities to recognize</th>
<th>Random Guess (%)</th>
<th>Total Accuracy (%)</th>
<th>Total Accuracy (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All (51)</td>
<td>1.9%</td>
<td>87.9</td>
<td>50.6</td>
</tr>
<tr>
<td>All with no intensities (31)</td>
<td>3.2%</td>
<td>91.4</td>
<td>72.0</td>
</tr>
<tr>
<td>Postures, ambulation and two MET intensity categories (11)</td>
<td>9%</td>
<td>96.5</td>
<td>81.3</td>
</tr>
<tr>
<td>Postures and Ambulation with no intensity (8)</td>
<td>12.5%</td>
<td>98.4</td>
<td>92.9</td>
</tr>
<tr>
<td>Postures (4)</td>
<td>25%</td>
<td>99.3</td>
<td>98.0</td>
</tr>
</tbody>
</table>
Lab validation experiments

- Lab
- Lab + some everyday activities
- “Obstacle course” datasets

- Wockets
- Mobile phone
- MITes
- Oxycon Mobile
- GPS
- Zephyr
- Actigraphs
- Sensewear
- RTI environmental
- Columbia environ.

Approximate locations
Detect activity type in real-time
Detect activity in real-time

Working on port to Android phones
Wockets: last cost estimate

- In quantities of 100 (researchers build)
  - Wocket: $63
  - Band: $4.50
  - Charger: $28

- System (without phone):
  4 Wockets, 4 bands, charger: ≈$298

(Single Actigraph GT3X: $300+)
Are you scratching your head?

“Just a Bluetooth accelerometer”
“Why didn’t you add a [pick a sensor]”

• Yes, but...
  – While each part is simple, the system is not; all design decisions are inter-related
  – Lab prototype is the easy part; robust deployment is the hard part!
  – Cost and field validation are key
Challenges we’ve had

• Bluetooth limitations on phones
• Avoiding feature/cost creep
• Thin+waterproof+inexpensive+low volume
• Battery life (on phones)
• Minimizing participant burden
• Remote data validation tools
• Robustness in all conditions
What health researchers say

• **Like** lower price than gold standard

• **Unsure** about new capabilities
  – Intrigued about improving what they measure
  – Uncertain about data-driven discovery and new information (“fishing expeditions”)

• **Dislike** higher risk
  – Require validation studies
  – Want comparison with common measures
Planned validation study

• 50 subjects (considered small)

• Wear Wockets system daily for 4 months
  – Use remote compliance monitoring tools
  – Gold standard comparison tricky

• Continue wearing Wockets (up to 4 mo)
  – No prompting from staff
  – Phone encourages compliance
Take away

• Wockets designed to meet a need for a field-deployable, low-cost, real-time, wearable physical monitoring system with remote management

• Expect affordable systems soon for longitudinal, remote data collection of type, intensity, duration, and location of physical activity using mobile phones
For more information

- Wockets (Join us!)
  http://web.mit.edu/wockets

- Send me email:
  s.intille@neu.edu

- Ask me about Northeastern’s new transdisciplinary Ph.D. in Personal Health Informatics!
  http://phi.neu.edu