Novel techniques for monitoring aging adults in-situ

Octav Chipara
Department of Computer Science
Part of the Aging Mind and Brain Initiative

https://cs.uiowa.edu/~ochipara
Patient behavior and health

• Patient behavior and their health are inexorably linked

• **Understanding behavior ↔ health relationship** would allow us to:
  • **develop new diagnostics techniques**
    • e.g., assessment of memory, mood, activity level to detect onset of Alzheimer’s disease
    • e.g., assessment of social interactions for depression in assisted living
  
  • **evaluate the efficacy/impact of medical treatment**
    • e.g., cognitive behavioral therapy for depression
    • e.g., impact of drugs on quality of life
Monitoring patient behavior with manual data collocation

- Manual data collection is the gold standard ...
  - subjective (e.g., memory bias, Hawthorne effects)
  - poor scalability
    - low temporal resolution
    - cannot monitor many subjects
  - people are expensive!

- ... but, our tools fundamentally limit our understanding
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We need better measurement tools!
New methods: Mobile Technology + Sensors

- **Assesses behavioral states**
  - with objective metrics
  - in real-time
  - in-situ
  - enable longitudinal studies with large patient populations

- **However, key engineering challenges remain**
  - reliable wireless communication
  - coping with unreliable sensors
  - fusing multiple sensor streams
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These challenges are shared by many mHealth systems!
Challenge:

Reliable wireless communication
(without infrastructure)
Infusing technology into emergency response workflow

- Communications using radios & paper
  - Error-prone and labor-intensive
  - Slow dissemination of information

Triage tag

Example Coordination

Medcom
Infusing technology into emergency response workflow

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Infusing technology into emergency response workflow

- Mobile technology improved information quality
  - identical time to triage patients
  - reduced the rate of missing/duplicate patients
Challenge: Reliable communication

• Initial approach: required deployment of infrastructure
  • poor performance due to incomplete coverage
  • as little as 10% of the data delivered
• Peer-to-peer communication architecture:
  • requires no infrastructure, mobile phones communicate directly
  • epidemic propagation of information
• UCSD drill: 19 first responders triaging 41 victims
  • 98% reliability during the drill
Challenge:

Coping with unreliable sensors
Detecting clinical deterioration in general hospital units

• Early detection of clinical deterioration
  • clinical deterioration is often preceded by changes in vitals

• Real-time patient monitoring is required
  • wired patient monitoring ➞ inconvenient
  • wireless telemetry systems ➞ too expensive for wide adoption
  • most general hospital units collect vitals manually and infrequently
Detecting clinical deterioration in general hospital units

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Goal: **reliable** and **real-time** wireless clinical monitoring for **general** hospital units
Clinical deployment

Step-down cardiac care unit
41 patient monitored
System reliability

- Network reliability per patient: 99.68% median, range 95.2% - 100%
- Sensing reliability per patient: 80% median, range 0.46% - 97.69%
  - 29% of patients with sensing reliability < 50%
- System reliability dominated by sensing reliability!
Challenge: Sensor reliability

- Automatically notify a nurse after receiving no valid data for a time
  - balance nursing effort and reliability gain
  - at 15 min timeout
    - ➞ 1.55 interventions per patient, per day
    - ➞ 100x more data per day

Sensing reliability with different timeouts

# of alarms per patient, per day

[Graph showing fraction of patients vs. reliability with different timeouts and number of alarms per day vs. sensor disconnection threshold (min)]
Challenge: Sensor reliability

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Sensing reliability with different timeouts

# of alarms per patient, per day

<table>
<thead>
<tr>
<th>Reliability (%)</th>
<th>0</th>
<th>10</th>
<th>20</th>
<th>30</th>
<th>40</th>
<th>50</th>
<th>60</th>
<th>70</th>
<th>80</th>
<th>90</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fraction of patients (%)</td>
<td>0</td>
<td>10</td>
<td>20</td>
<td>30</td>
<td>40</td>
<td>50</td>
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</tr>
</tbody>
</table>

Sensor disconnection threshold (min)
Results

- Reliable two-tier architecture: 99.68% reliability per patient
- System reliability is dominated by sensing errors
  - Complementary mechanisms for combating sensing errors
    - Oversampling
    - Disconnections alarms
  - Reduced patient with low reliability (<70%) from 42% to 12%
- Produces two orders of magnitude more data than possible through manual data collection
- Continuous data collection for 3 days without changing batteries
Challenge:

Fusing streams of sensor data
EgoSense: a tool for large-scale longitudinal studies

- Today, patient behavior is tracked through activity logs, surveys, videos
  - impossible to perform longitudinal in large patient populations
- EgoSense will track patient behavior in the real world and in real-time
  - patient activities will be classified based on their physical + social components

<table>
<thead>
<tr>
<th>PHYSICAL ACTIVITY</th>
<th>SOCIAL ACTIVITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sedentary</td>
<td>Proximity, No Interaction</td>
</tr>
<tr>
<td></td>
<td>seated alone</td>
</tr>
<tr>
<td></td>
<td>(eating, watching TV, alone)</td>
</tr>
<tr>
<td></td>
<td>seated in proximity of others but not conversing</td>
</tr>
<tr>
<td></td>
<td>(eating, watching TV in proximity of others, without conversing)</td>
</tr>
<tr>
<td></td>
<td>seated in proximity and conversing</td>
</tr>
<tr>
<td></td>
<td>(eating, watching TV, card game while conversing)</td>
</tr>
<tr>
<td>Mobile</td>
<td>Social interaction</td>
</tr>
<tr>
<td></td>
<td>moving while alone</td>
</tr>
<tr>
<td></td>
<td>(chores, bathing, walking, jogging)</td>
</tr>
<tr>
<td></td>
<td>moving in a group without conversing</td>
</tr>
<tr>
<td></td>
<td>(taking a walk/bowling/playing tennis with friends)</td>
</tr>
<tr>
<td></td>
<td>moving in a group and conversing</td>
</tr>
<tr>
<td></td>
<td>(taking a walk/strolling/shopping while conversing)</td>
</tr>
</tbody>
</table>

- simplifies that sensing task as activities with similar sensor traces will be classified in the same state
EgoSense system

- **Components:**
  - mobile phones carried by patients: accelerometers + proximity + sound
  - environmental sensors: notebooks with proximity + sound
- **Social interaction:** inferred using proximity and speaker identification
- **Physical activity:** measured using accelerometers
Challenge: Sensor fusion

• How to split the sensing & computation affects accuracy and energy efficiency
  • sensors may provide redundant information ➞ turn off unnecessary sensors
  • environment sensors are power ➞ preferential use
  • analysis come at different costs (e.g., proximity vs speaker identification)
    ➞ select the most energy efficient analysis
Conclusions

- **Mobile technology and sensors will transform behavioral studies**
  - enable large-scale longitudinal studies
  - open new venues for diagnostic, measurement of patient outcomes, QOL

- **Significant engineering challenges remain:**
  - reliable wireless communication
  - coping with sensor failures
  - sensor fusion and adaptation

- **Developing mHealth systems require engineers and clinicians to collaborate:**
  - understand what are the clinically relevant information that must be collected
  - develop a minimally invasive system to collect these measurements
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Questions?
Potential for detecting clinical deterioration

Bradycardia

Pulmonary edema

Sleep apnea
Robert Hooke’s Microscope (circa 1660)
Robert Hooke’s Microscope (circa 1660)  
Behaviorscope (circa 2010)