Mobile (Health) Applications

Octav Chipara
Agenda

• Sign up for the new group
• Today => talk about applications
• Next lecture => start talking about embedded programming and Android dev
  • setup your Eclipse environment!
How to come up with interesting projects

• Identify a high level problem to solve (aka the people’s problem)
• Identify the technical challenges you have to address (aka the engineer’s problem)
• Develop a solution that solves the engineer’s problem
• Identify the novel aspects of your approach
  • might be the problem itself (high impact) or a better solution to the problem
• Evaluate your solution
  • most often from a technical perspective
  • better if you relate it to its impact of the “people’s problem”
Clinical Monitoring
Detecting clinical deterioration at low cost

- Clinical deterioration in hospitalized patients
  - 4-17% suffer adverse events (e.g., cardiac or respiratory arrests)
  - up to 70% of such events could be prevented.
- 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
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Goal: reliable and real-time wireless clinical monitoring for general hospital units
Wireless sensor networks vs. Wi-Fi

• Commercial telemetry systems (Phillips, Cisco, GE):
  • Wi-Fi ➡ single-hop wireless, wired backbone
  • adoption limited to specialized hospital units

• Benefits of wireless sensor networks
  • more energy efficient than Wi-Fi at low data rate
    • common vital signs have low data rate
    • nurses are too busy to change batteries!
  • low deployment cost
    • eliminate wired infrastructure ➡ mesh networks
    • ➡ ease of adoption (e.g., field hospitals, rural areas)
  • reliability of wireless sensor networks - an open question!
Related work

- **Wireless sensor networks for medical applications**
  - Assisted living: ALARM-NET
  - Disaster recovery: AID-N, CodeBlue, WIISARD
  - Emergency room: MEDISN, SMART
  - Motion analysis: Mercury
- **Numerous systems, limited results from clinical deployments**

**Images:**
- MEDISN, John Hopkins
- Code Blue, Harvard
- Code Blue, Harvard
Related work

- Wireless sensor networks for medical applications
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First holistic reliability study performed in a hospital unit using sensor networks

MEDISN, John Hopkins

Code Blue, Harvard

Code Blue, Harvard
System architecture

- **Base-station**
  - laptop that will store medical data

- **Relay nodes**
  - redundant deployment:
    - coverage
    - fault-tolerance
  - plugged into wall outlets

- **Patient nodes**
  - pulse oximeter + microcontroller + radio
  - same pulse-oximeter as used in hospitals
  - battery powered
Reliable network architecture

- **Initial solution:** use CTP\(^1\) all nodes in the network
- **Insight:** isolate the impact of mobility
- **Solution:** two-tier architecture for end-to-end data delivery

- **Dynamic Relay Association Protocol (DRAP): Patient \(\rightarrow\) 1st relay**
  - DRAP used on mobile nodes \(\rightarrow\) dynamically associate relays
  - single-hop protocol handles patient mobility
  - simplify power management in patient nodes (send only)

- **Stationary relay network: 1st relay \(\rightarrow\) ... \(\rightarrow\) base station**
  - CTP used on fixed nodes \(\rightarrow\) reuse well-tested CTP
  - wall-plugged \(\rightarrow\) no need to worry about energy

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\[1\] O. Gnawali et. al., **Collection Tree Protocol.** SenSys 2009
Clinical deployment

- **Step-down cardiac care unit**
  - 16 patient rooms, 1200 m²

- **Network**
  - 18 relays: redundant network
  - longest path: 3-4 hops
  - channel 26 of IEEE 802.15.4

- **HR and SpO2 collected every 30/60s**
  - disposable adult probes
  - data not available to nursing staff

- **46 patients enrolled**
  - 41 days in total, 2-68 hours per patient
  - up to 3 patients at a time
  - 5 patients excluded from analysis
Potential for detecting clinical deterioration

Bradycardia

Pulmonary edema

Sleep apnea
System reliability

- Network reliability per patient: 99.68% median, range 95.2% - 100%
  - effectiveness of two-tier DRAP/CTP network architecture
- Sensing reliability per patient: 80% median, range 0.46% - 97.69%
  - 29% of patients with sensing reliability < 50%
- System reliability dominated by sensing reliability!
Reliability metrics

valid reading

invalid reading
Reliability metrics

valid reading

invalid reading

time-to-failure
Reliability metrics

- valid reading
- invalid reading

- time-to-failure
- time-to-recovery
Sources of sensing errors

Hand movement

Improper placement
Automatic detection of clinical deterioration

- **Sample**: 29 with significant cardiac/pulmonary problems and 7 without
- **CUSUM**: partitions time series into chunks with similar statistical props.
- **Chunk features**: 5th- and 95-percentiles, slope of linear fit
  - deterioration detected by comparison with thresholds

![Diagram showing ROC curve with point at (0.8, 0.8) indicating 79.3% sensitivity]
Activity Sensing in the Wild:
A Field Trial of UbiFit Garden
In U.S., Majority Overweight or Obese in All 50
Quantifying physical activity

- Most physical activity is tracked either through journaling or with pedometers
  - journals are often incomplete or inaccurate due to memory bias

- Increase awareness of the amount of exercise performed
  - measure the amount of physical activity performed
    - pre-planned activity: Wii Fit, Dance Dance Revolution, etc.
    - simple continuous measurements: step counts
    - classification of the type of physical activity: running, walking, biking, etc.

- Improve patient compliance with increases in physical activity
  - develop an user-friendly interface to manage patient goals
  - develop visualization approaches to track goals
  - engage patients within their community and friends
Technical challenges

- Collection of raw measurements from sensors
- Minimize the energy consumed on sensors and mobile phone
- Upload data to server for archival
- Effective user interface
  - users may input the activities they perform
  - feedback regarding the amount of activity performed by the user
Sensors

MSP Features
Built on iMote2
Linux OS
32MB RAM
2 GB Flash Storage
Zigbee and Bluetooth
12-16 hours battery life

10 Built-in Sensors
3D Accelerometer
2D Compass
Barometer
Humidity
Visible light
Infrared light
Temperature
System architecture

1. Collect raw sensor readings
   - Generated at varying rates

2. Calculate features
   - Generated at 1/4 second intervals

3. Produce margins
   - Mean, median, range, etc.
   - Measure of confidence for particular activities

4. Smooth margins into meaningful activities
   - Smoothing is defined at the application level

5. Send margins to phone via Bluetooth
Manual activity reporting

1. Would you like to enter activity to your journal for yesterday?
   1. Yes
   2. No, I’m done for now

2. Did you do the activity:
   1. Today
   2. Yesterday
   3. Oops! - Exit Journal

3. What type of activity did you do:
   1. Cardio
   2. Walking
   3. Strength Training
   4. Flexibility Training
   5. Other

4. What type of cardio activity did you do:
   1. Running
   2. Cycling
   3. Elliptical trainer
   4. Stair climber
   5. Cardio class
   6. Swimming
   7. Roller-blading / Skating
   8. Hiking
   9. Rowing
Glanceable display - providing instant feedback

- intuitive - no raw sensor data!
  - a flower for each activity
  - type of flower indicative of activity type
  - height determined by aesthetics
- positive enforcement
- engaging
- evaluated through user surveys
Evaluation

Figure 5. Frequency of performed activities & how recorded for each participant—“performed activities” include inferred (unchanged and edited) and manually journaled activities.
Aging in place

- There are over 36 million seniors over the age of 65
  - over 10 million live alone
  - fastest growing demographic group in the U.S.
- The vast majority (95%) of seniors want to “age in place” -- live in
  - their own homes
  - the burden on family caregivers is severe
  - 25% of families care for someone outside the home
  - 30% of elderly admissions to a nursing home or assisted living facility
  - occur not because of deterioration in the senior’s condition but
  - because of caregiver burnout
  - Homecare costs borne by family, institutions, and government are soaring.
- Federal Medicaid spending for home and community-based care was
  - $24.7 billion in 2002
Categorizing Physical Activity
Technical challenge

• **Goal:** determine physical activity based on sensor readings
  • physical activity = {sitting, running, biking, watching TV, etc.}

• **Challenge:** many activities look alike if you have a single sensor or sensing modality

• **Approach: sensor fusion**
  • fuse data across multiple devices (of same kind) with different locations
  • fuse data across multiple sensing modalities (e.g., EKG)
Practical physical activity recognition

- 2 subjects, 2 weeks
  - Android Phone
    - 3-axis accelerometer, WiFi/GPS Localization
- 5 IRIS Sensor Motes
  - 2-axis accelerometer, light, temperature, acoustic, RSSI
Practical physical activity recognition

Sensor Configuration

Runtime Control and Feedback

Ground Truth Logging
Experiments

• Classify typical daily activities, postures, and environment
• 2 subjects over 2 weeks
• Classification Categories:

**Environment:**
Indoors, Outdoors

**Posture:**
Cycling, Lying Down, Sitting, Standing, Walking

**Activity:**
Cleaning, Cycling, Driving, Eating, Meeting, Reading, Walking, Watching TV, Working
Classification Performance

Posture Classification Accuracy

Runtime Accuracy

- Total
- Walking
- Sitting
- Standing
- Cycling
- Lying

Subject 1
Subject 2
Classification Performance

Activity Classification Accuracy

<table>
<thead>
<tr>
<th>Activity</th>
<th>Subject 1</th>
<th>Subject 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cleaning</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cycling</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Driving</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eating</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Meeting</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reading</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Walking</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Working</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

RunTime Accuracy

Tuesday, August 28, 12
Smoking Kills

- Causes cancer in different organs throughout the body
- leads to cardiovascular and respiratory diseases
- harms reproduction

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In US alone

Tobacco is the cause for **one of every five deaths**

Smokers **die 13-14 years younger**

Public health burden of **$193 billion annually**
Self-Quitting is NOT an Option

- The 6 month quit rate was 3-5% in 5 of the 6 studies

• **Eight (out of 27) divisions** at NIH award research grants for smoking cessation programs

• **NIH** alone awards **$350+ million annually** in smoking research\(^1\)

• **Still, smoking continues to be prevalent**
  – Each day about 3,000 people become new daily smokers  
  – Success rate of most smoking cessation programs is less than 10%

• **The reason seems to be**
  – Most research are self report based that introduces bias  
  – NO reliable method to detect smoking and intervene at the right moment

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[1] Estimates of Funding for Various Research, Condition, and Disease Categories (RCDC), NIH  
  (http://report.nih.gov/categorical_spending.aspx)
Current State of the Art

• Devices are available that measure and display/store CO levels in a single breath exhaled through a mouthpiece attached to them
• piCO+/Micro+ are designed for use as motivational aid
• CReSS is used to observe smoking patterns and the degree of tobacco intake
• Requires compliance from the users
• May cause embarrassment using in front of others

DOES NOT DETECT SMOKING & CANNOT PROVIDE REAL TIME INTERVENTIONS
AutoSense System for Data Capture in Field

Continuous Assessment of Physiology, Stress, and Addictive Behaviors in Field

Ten wireless sensors in two wearable units

Armband sensors: Alcohol (WrisTAS), Temp., GSR, Accelerometer

Chestband sensors: ECG, Respiration, GSR, Ambient & Skin Temp., Accelerometer

Long lifetime (10+ days)

Inferences from Respiration

• Inference of Conversation and Stress from respiration is shown to be possible\(^1,2\)
  – Most smokers smoke during conversations and with other smokers
  – Stress has been found to be a predictor of smoking
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• Real time detection of smoking opens up the opportunity for
  • **Analysis of contexts of smoking**
  • **Finding true predictors of smoking**
Concept of mPuff
Concept of mPuff

Respiration Chest Band
Concept of mPuff

Respiration Chest Band

Tuesday, August 28, 12
Concept of mPuff

Respiration Chest Band

Cell Phone Captures Signal
Concept of mPuff

Respiration Chest Band

Cell Phone Captures Signal

Smoking puff detection
Key Contributions
Show puff detection is possible from respiration
Show puff detection is possible from respiration

Identify several new respiration features
Key Contributions

Show puff detection is possible from respiration

Identify several new respiration features

Open up research on automated smoking detection
System Overview

• Features
  • Computed from each cycle

• SVM Classifier
  • Trained using carefully labeled data

• Semi-Supervised Classifier
  • Utilizing the data collected in natural environment
Features

![Graph showing signal amplitude over time](image)
Features

Inhalation Duration
Features

Exhalation Duration

Inhalation Duration

Stretch
IERatio = Inhalation Duration / Exhalation Duration

Respiration Duration = Inhalation + Exhalation Duration
Respiration during Smoking
Respiration during Smoking

PUFFS

Signal Amplitude vs. Time (Seconds)
Respiration during Smoking

Compared to Non-puff cycles PUFFs have:

- HIGH Stretch
- Similar upper & lower parts
- Relative to neighboring cycles significant change in stretch and other features
New Features (1)

Stress Speaking

Smoking

Tuesday, August 28, 12
New Features(1)

- Stress
- Speaking
- Smoking

Tuesday, August 28, 12
Unlike Conversation or Stress, SMOKING PUFF Cycles have

- LONGER Stretch
- Symmetric across the mid-axis
- Significant relative change in stretch and other features
New Features (2)

![Graph of signal amplitude over time for running and smoking activities.](image)
Unlike Running
SMOKING PUFFS Cycles

- Significant relative change in stretch and Exhalation Duration
Aging in place
TELECARE STRATEGIES

Smart Sensors

Only required information leaves home

Local Processing

Local Intelligence

Emergency Services
Architecture

PDAs

Patient Interface

Body Networks

Emplaced Sensor Network

Backbone

Back-End Database

Internet

Nurses Stations

Human Interfaces
Smart homes
Circadian rhythms

Is there a mapping between circadian rhythms and disease?
Data from real patients
Social Activity Recognition
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>
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</thead>
<tbody>
<tr>
<td>Sedentary</td>
<td>Alone</td>
</tr>
<tr>
<td></td>
<td>seated alone</td>
</tr>
<tr>
<td></td>
<td>(eating, watching TV, alone)</td>
</tr>
<tr>
<td>Mobile</td>
<td>Moving while alone</td>
</tr>
<tr>
<td></td>
<td>(chores, bathing, walking, jogging)</td>
</tr>
<tr>
<td></td>
<td>Proximity, No Interaction</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>
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<tr>
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- 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