IoT for Healthcare

Trade-Offs Between Diagnosis and Usability

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Agenda

1. IoT for Healthcare
2. Stakeholders and their Interests
3. Example Conflict of Objectives: Diagnostic Information vs. Energy Consumption
4. Approach 1: Sensor Selection
5. Approach 2: Data Preselection
6. Conclusion
IoT for Healthcare
Why to Continuously Monitor Vital Signs?

Example 1: Atrial fibrillation
Duration of an AF episode: mostly < a few minutes

⇒ Diagnosis of diseases with transient symptoms
Why to Continuously Monitor Vital Signs?

Example 2: Acute cardiac decompensation

Regular follow-ups: every 3–6 months
Time for development of acute decompensation: ~ 1–2 weeks

⇒ Improved therapy by quick adaptation to the patient’s needs
  - Sensor–actor systems
  - Feedback to patient
  - Feedback to treating physician

Desired early detection of health status worsening
Hospitalizations
Why to Continuously Monitor Vital Signs?

Example 2: Acute cardiac decompensation

Sensors

- Intracardiac ECG (morphology & heart rate)
- Activity
- Thoracic impedance
- Intracardiac impedance
- Blood pressure
- Body weight

L. Wang, Am. J. Cardiol. 99 (10), Suppl., 2007, S3-S10
Example 3: Activity Classification

Purpose: Context information for interpretation of other sensor data
Indicator for decreased physical capability

Challenge: Properly distinguish different states of physical/mental load and disease-related causes
  e.g. – running
  – recumbent bike
  – exciting movie
  – cardiac disease

⇒ Fusion of different sensors / IoT devices needed
   for sensitive and specific diagnostic markers and context information
### The Top 10 in Burden

<table>
<thead>
<tr>
<th>Disease</th>
<th>Lifetime prevalence [%]</th>
<th>Fraction of deaths [%]</th>
<th>Fraction of costs [%]</th>
<th>Fraction of YLD metric [%]</th>
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<tbody>
<tr>
<td>Hypertensive heart disease</td>
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Ranges indicate different published figures. Cancer not considered.

## Comorbidities

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<th>Condition</th>
<th>Hypertensive heart disease</th>
<th>Atrial fibrillation</th>
<th>Diabetes mellitus</th>
<th>Ischemic heart disease</th>
<th>COPD</th>
<th>Asthma</th>
<th>Dementia</th>
<th>Kidney disease</th>
<th>Stroke</th>
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Conclusion

Purpose continuous disease monitoring
- Diagnosis of diseases with transient symptoms
- Improved therapy by quick adaptation to the patient’s needs

Diseases for continuous disease monitoring
- Diseases with transient symptoms
- Chronic diseases (cardiovascular, respiratory, renal, metabolic, mental)
- Keep comorbidities in mind!

IoT for continuous disease monitoring
- Sensor fusion for discrimination of different situations in daily life and different disease states
Stakeholders and their Interests
Stakeholders and their Interests

- **Patient**
  - Diagnostic/Therapeutic quality
  - Integrability into daily life

- **Treating Physician**
  - Diagnostic/Therapeutic quality
  - Integrability into clinical routine

- **Producer**
  - Profit from investments

- **Health Insurances**
  - Reduced costs for diagnosis & treatment

- **Regulatory Authorities**
  - Ethical aspects, particularly patient safety
## Stakeholders and their Interests in Summary

### Diagnostic/Therapeutic quality
- Signal quality
- Data evaluation quality
- Robustness
- Full coverage
- Effectiveness of treatment

### Integrability into daily life
- Non-stigmatization
- Light weight, small size
- Long battery life
- No long cables

- How to achieve sufficient functionality with limited energy?

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Argus® II retinal prothesis system
[http://www.secondsight.com]
Example Conflict of Objectives: Diagnostic Information vs. Energy Consumption
Conflict of objectives

Diagnostic information
- Increase number of sensors for more information
- Increased amount of transmitted data for data fusion

Battery lifetime
- Decrease number of sensors
- Decrease amount of transmitted data... for lower power consumption
Approach 1: Sensor Selection
Idea

When selecting the sensors for diagnosis, consider both ...

- relevance for diagnostic purpose and
- power consumption
Example Activity Classification: Concept

Sensor Platform
- Sensors: accelerometer
gyroscope
barometer
- Sensor position: upper back
- Arduino micro

Power consumption of sensor modules
- Gyroscope 11,880 μW
- Accelerometer 1,650 μW
- Barometer 3 μW

⇒ Power consumption dominated by gyroscope

MPU-6000 and MPU-6050 Product Specification Revision 3.4, InvenSense, Inc.
MS5611-01BA03 Barometric Pressure Sensor, with stainless steel cap, Measurement Specialties, Inc.
Example Activity Classification: Methods

Activities for Classification
– Standing
– Walking in the flat
– Walking upstairs / downstairs
– Jogging

Study Population
– $N = 20$ (9/11 male/female)
– $24 \pm 4$ years old (21–38yr)

Data Analysis
– 261 features derived from sensor data
– $k$ nearest neighbor algorithm
– Optimization w.r.t. F1 score
Example Activity Classification: Results

<table>
<thead>
<tr>
<th>Sensor combination</th>
<th>A+G+P</th>
<th>A+G</th>
<th>A+B</th>
<th>G+B</th>
<th>A</th>
<th>G</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>F1 score [%]</td>
<td>95.7</td>
<td>95.1</td>
<td>95.0</td>
<td>93.6</td>
<td>91.4</td>
<td>90.9</td>
<td>62.1</td>
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<tr>
<td>Power consumption [mW]</td>
<td>13.5</td>
<td>13.5</td>
<td>1.7</td>
<td>11.9</td>
<td>1.7</td>
<td>11.9</td>
<td>0.003</td>
</tr>
<tr>
<td>Normal. computation time [%]</td>
<td>100</td>
<td>92</td>
<td>55</td>
<td>44</td>
<td>39</td>
<td>41</td>
<td>92</td>
</tr>
</tbody>
</table>

A: accelerometer; G: gyroscope; B: barometer

J. Kirchner, S. Faghih-Naini, P. Bisgin, G. Fischer, 2018 IEEE SENSORS, pp. 1-4

⇒ With reduced sensor set: power reduced by 88%  
   computation time by 45%  
   F1 score worsened by only 0.7%
Approach 2: Data Preselection
Idea

- Data pre-analysis “at the edge”
- Identify and transmit only data that might be diagnostically relevant
- Computationally demanding data analysis after data transmission
Example Detection of Atrial Fibrillation: Concept

- Identify data segments that might contain AF episodes
- Discard data segments with clear normal sinus rhythm (NSR)
- Optimize selection algorithm for maximum sensitivity
Example Detection of Atrial Fibrillation: Methods

Database
- PhysioBank: MIT-BIH Atrial Fibrillation Database
- 16 usable recordings from patients with AF (10h duration each)
- 184 AF episodes
- Fraction of AF of entire data: ~37 %

Detection Algorithm for preselection
- A-posteriori analysis
- Detection criterion:
  standard deviation of heart rate > threshold
- Optimization of free parameters w.r.t. max.
  sensitivity = \[ \frac{\text{# data segments with correctly detected AF}}{\text{# data segments with AF}} \]
- Alternative optimization (“stand alone”):
  sensitivity = specificity

Example Detection of Atrial Fibrillation: Results

<table>
<thead>
<tr>
<th></th>
<th>“Preselection”</th>
<th>“Stand-alone”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitivity</td>
<td>99.6 %</td>
<td>89.3 %</td>
</tr>
<tr>
<td>Specificity</td>
<td>38.4 %</td>
<td>89.3 %</td>
</tr>
<tr>
<td>Episode sensitivity</td>
<td>100 %</td>
<td>100 %</td>
</tr>
<tr>
<td>Data reduction (off all data)</td>
<td>26.4 %</td>
<td>61.1 %</td>
</tr>
<tr>
<td>Data reduction (off NSR)</td>
<td>38.4 %</td>
<td>89.5 %</td>
</tr>
</tbody>
</table>


› Reduction of non-AF data with simple “preselection” algorithm by 38% with “stand-alone” algorithm (higher specificity) by 90%
Conclusion
Conclusion

Potential Benefits
− Diagnosis of diseases with transient symptoms
− Improved therapy by quick adaptation to the patient’s needs

Potential Conflicts
− Amount of data: functionality vs. power consumption
− Personal data: data protection vs. data for product improvement
− ...

Potential Solutions
− Sensor selection
− Data preselection (data evaluation “at the edge”)
Thanks a lot for your attention!

Questions?