Remote patient monitoring for health status assessment

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Outline

• Introduction
  – eHealth /mHealth in a nutshell
  – Statistics and deployment approaches with examples

• Health state models
  • Human health state model
  • Dynamic human health state model

• Remote patient monitoring

• Health state assessment

• Health state visualization
  – Human health state visualization
  – Population health state visualization

• Conclusions
Óbuda University

- 5 faculties
- 13,000 students
- 2nd biggest technical university in Hungary
Monitoring human individuals remotely

Motivations

• Problems
  – Large rural areas, non-accessible areas
  – Aging population, longer life expectancy,
  – Healthy long living (prevention)
  – Costly health problems: cardiac problems, neurodegenerative
disease issues: Alzheimer, Parkinson’s
  – Sparse/Limited resources: nurses/doctors, beds at hospital,
equipments (ECG devices), connectivity
eHealth/mHealth

eHealth (e-health):
stands for healthcare practice supported by electronic processes and communication (’99)
1 term ➔~50 definitions

• Hot topics
  – EHR/PHR – Electronic Health Record
  – eLearning in Health
  – Computerized physician order entry
  – ePrescribing
  – eHealth analytics and big data in health
  – Clinical decision support systems
  – Consumer health informatics
Hot topics in eHealth (contd.)

• Telemedicine: physical and psychological diagnosis and treatments at a distance, including telemonitoring of patients functions;

• mHealth: the use of mobile technologies to support health information and medical practices. It holds great potential for facilitating the transformation of health services and data delivery by reaching wide geographical areas and in portable forms.
Main eHealth approaches

• Bottom-up
• Building block approach
• Education focus
• Top down with clear visions
  – eHealth strategy, with concrete plans
eHealth in Europe

- 84% - national universal health coverage policy or strategy
- 70% national eHealth policy or strategy
- 69% - financial support available specifically for the implementation of their national eHealth strategy.
- 89% - universities or technical colleges teach students how to use information and communication technologies and eHealth,
- 82% - teach professionals how to use information and communication technologies and eHealth
mHealth in Europe

• Capturing and transmitting data to monitor patient conditions via mHealth is
  – a key growth area across Europe.
  – In 2015 70% (32 countries) report using mHealth for patient monitoring.
  – The patient monitoring programmes operate as established (37%), local-level (43%) and pilot programmes (47%).
eHealth building blocks

- Infrastructure (connectivity)
- Software + services
- Devices
- Human Elements
  - Digital Literacy (basic reading and writing)
  - Education
    - Practitioners
    - Patients
    - Service Providers (new workflows, business models)

- Sustainability is a key factor!
Remote patient monitoring
Sensor data handling

- **Data Acquisition (DAQ)**
  - Single/multiple sensors
- **Data management**
  - Processing/filtering
- **Store and retrieve**
- **Visualization**
- **Data sharing**

What if setup is unknown?
Remote patient monitoring architecture
Measured biosignals/sensor data

• Acquired data:
  – Actual temperature of the human individual is 40° C.
  – Blood oxygenisation level is 98%.
  – Blood glucose level is 6.6.
  – Accelerometer has reported a 1 g movement to Az.
  – Patient does not moved since 6 hours.
  – Patient’s hand moved 1 cm.
  – Patient’s hand oscillate 1 cm with an average amplitude.
  – ECG diagrams show heart fibrillation

Are these values bad or good? How accurate?
Animal and vegetation health state models

• Objective health state assessment is difficult
  – Data collection → Data fusion (convert information in a common format/space) → Data evaluation

• Examples
  – BC (Body Condition) scoring methods for animal experiments (mouse, rat, etc.)
    • based on easy-to-measureable parameters (body weight, external marks, physical appearance, responses to external stimuli) using 1-4 /1-10 grading levels
  – Vegetation Health Indices (VHI) combine estimation of moisture and thermal conditions. VH (VHI, VCI, TCI)
    • using high resolution radiometer satellite images
Human patient health state models

- Disease specific scoring schemes
  - COPD Assessment Test (CAT)
  - Medical Research Council dyspnoea scale (mMRC)
    - Data: SpO2 (pulse oximeter), blood glucose level (blood glucose meter), FEV1 (spirometer)

- Scoring schemes derived from statistical data analysis
  - Diabetes risk scores
    - Data: height, weight, age, gender, lifestyle, ...

- State-transition modeling (STM)
  - Health states & transitions
Health Metric (HM)-space

Health Metric (HM)-space: dimension-less information space.

Measured sensor data $\rightarrow$ conversion into this HM-space

The HM space provides information how big the difference between the measured parameter value and a pre-defined reference scale.

The conversion builds up from two parts: a normalization, and make it dimension-less and do a distance calculation.
Health state model in information space

• Can change constantly, as remote monitoring data arrives
• Supports non-stop DAQ and processing
  – Measured data conversion into HM - space
• Can built up from arbitrary type and amount of sensor data
• Can incorporate historical data
• Can incorporate individual and population level parameter impact values
Human health state model

- $S$ dimension-less value (in HM-space) can be calculated from the measured sensor parameter value.

\[ S = \sum_{k=1}^{R} \Delta Z_k \cdot F_k \]

\[ HM_j = \sum_{i=1}^{NK} S_i \cdot w_i \leq C \]

\[ \sum_{i=1}^{NK} w_i = 1 \]

\[ HM_{\text{TOTAL}} = \sum_{j=1}^{T} HM_j \]
Dynamic human health state model

- Let $V_{1..M,t}$ be values of $P$ parameter at $t \in [t_0, t_a]$, until $t_a$ actual time instance.
- Let $P_i$ parameter defined in time $t$ by $V_{j,t}$ using the following equation:

$$P_i = \sum_{j=1}^{M} \left[ F_P(V_{j,t}) \ast \frac{D_P}{(t_a - t_m) + 1} \right]$$

- Where $D_P$ is the decay function of parameter $P$, $t_m$ the time instance when the measurement was done, $t_a$ is the actual time instance, let $F_P$ be the quality function of the $V_{j,t}$ value.

$$P_{i_{AVG}} = \frac{\sum_{j=1}^{M} \left[ F_P(V_{j,t}) \ast \frac{D_P}{(t_a - t_m) + 1} \right]}{M}$$
Health state calculation workflow

Sensor → Measure data

- Locate appropriate parameter axis in HM space
- Scale value according to the axis unit
- Mark the measurement value on the axis
- Color the axis according to the thresholds

Personal threshold profile
Sensor → Measure data

Locate appropriate parameter axis in HM space → Scale value according to the axis unit → Mark the measurement value on the axis → Color the axis according to the thresholds

Data type dependent
Threshold profile functions → Personal threshold profile

Calculate HM score for the measured value → Personal data type impact profile (optional) → Personal sector impact profile

Calculate HM score for the sector → Calculate Total HM score
Remote patient monitoring

Requirements

- Multimodal sensor monitoring
- Many different
  - Data type
  - Value unit
  - Scale
- Adaptable
- Personalizable
- Generic visualization
DAQ software
-DAQit software suit-

• Targets
  – Diabetes, Hypertension, Cardiac diseases
  – Obesity/bulemy monitoring
  – Domestic assistance: Panic/Emergency situations
  – Real-time sport activity monitoring

• Features
  – Full scale patient monitoring ecosystem
  – Client & Servers: data acquisition & visualization & processing
  – Multimodal: ~30+ different sensors
Sensor set

• COTS (Commercial off-the-shelf) sensors

• Sensor drivers at client side is written carefully
  – Huge work: incompatible, proprietary solutions
  – Sensors are protected by law (no reverse engineering 😞)
# Sensor sets

- **Diabetes monitoring**

<table>
<thead>
<tr>
<th>Model type</th>
<th>Manufacturer</th>
<th>Connection type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accu-check Active</td>
<td>Roch e Ltd.</td>
<td>Wired, via Smartpix™/USB Wireless infrared (via ir2voice™)</td>
</tr>
<tr>
<td>Myglucohealth</td>
<td>Myglucohealth Ltd.</td>
<td>Wireless, BTv2</td>
</tr>
<tr>
<td>Dcont Personal Optimum</td>
<td>77 Elektronika Ltd.</td>
<td>Wireless, infrared (via ir2voice™)</td>
</tr>
<tr>
<td>Dcont Partner</td>
<td>77Elektronika Ltd</td>
<td>Wireless, infrared (via ir2voice™)</td>
</tr>
<tr>
<td>Breeze II.</td>
<td>Bayer AG.</td>
<td>Wired, via USB</td>
</tr>
</tbody>
</table>
Sensor sets (contd.)

- **Hypertension monitoring**

<table>
<thead>
<tr>
<th>Model type</th>
<th>Manufacturer</th>
<th>Sensor type</th>
<th>Connection type</th>
</tr>
</thead>
<tbody>
<tr>
<td>UA-767 PBT</td>
<td>AND Ltd.</td>
<td>Blood pressure monitor</td>
<td>Wireless (BTv2)</td>
</tr>
<tr>
<td>BlueBP</td>
<td>Meditech Inc.</td>
<td>ABPM</td>
<td>Wireless (BTv2)</td>
</tr>
</tbody>
</table>

- **Cardiac monitoring**

<table>
<thead>
<tr>
<th>Model type</th>
<th>Manufacturer</th>
<th>Sensor type</th>
<th>Connection type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cardioblue</td>
<td>Meditech Inc.</td>
<td>Mobile ECG 5 ch</td>
<td>Wireless (BTv2)</td>
</tr>
<tr>
<td>Savvy</td>
<td>Savvy Inc.</td>
<td>Mobile Ecg 1 ch</td>
<td>Wireless (BTv2/v4)</td>
</tr>
</tbody>
</table>

- **Blood oxigenisation**

<table>
<thead>
<tr>
<th>Model type</th>
<th>Manufacturer</th>
<th>Sensor type</th>
<th>Connection type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Onyx II 9560</td>
<td>Nonin Medical Inc.</td>
<td>Pulse oxymeter</td>
<td>Wireless (BTv2)</td>
</tr>
</tbody>
</table>
### Sensor sets (contd.)

**Activity/movement monitoring**

<table>
<thead>
<tr>
<th>Model type</th>
<th>Manufacturer</th>
<th>Sensor type</th>
<th>Connection type</th>
</tr>
</thead>
<tbody>
<tr>
<td>HxM</td>
<td>ZephyrTechnology Ltd.</td>
<td>Pulse monitor</td>
<td>Wireless (BTv2)</td>
</tr>
<tr>
<td>Bioharness</td>
<td>Zephyr Technology Ltd.</td>
<td>DAQ harness: pulse, posture, R-R, Heart rate</td>
<td>Wireless (BTv2)</td>
</tr>
<tr>
<td>H6/H7</td>
<td>Polar Inc.</td>
<td>Heart rate sensor</td>
<td>Wireless (BTv4)</td>
</tr>
<tr>
<td>Quardio (Consumer electronic grade)</td>
<td>Quardio Inc.</td>
<td>Mobile ECG, GSR, temperature, pulse, breathing activity, 1 day</td>
<td>Wireless (BTv4)</td>
</tr>
</tbody>
</table>
When, how and what to measure
(Medical measurement protocols)

• Consensus protocols from healthcare professionals
  – Examples:
    • Hypertonia measurement protocol
      (72 hours, holter like)
    – Also described by computer readable format
      • Measurement sensor should be pre-programmed in advance
  – Basic protocol + additional measurement points,
    longer monitoring time, finer resolution
  – Long time to develop/acknowledged one
Visualization requirements

• Compare individual sensor data
  • To older parameter values
    • Visualize in a user-friendly way
    • To other individuals or to average population values
• Dynamic / real-time
• Multi-modal (many sensor type)
• Visualize sensor data at population scale
Biosignal visualization

Numerical data visualization example in tabled format

<table>
<thead>
<tr>
<th>Sensor name</th>
<th>ID</th>
<th>Temperature</th>
<th>Humidity</th>
<th>Last update</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>SHT</td>
<td>001</td>
<td>50  °C</td>
<td>30</td>
<td>2015-10-20 20:53:10:16544</td>
<td>OK</td>
</tr>
<tr>
<td>SHT</td>
<td>101</td>
<td>30.89  °C</td>
<td>44.1</td>
<td>2015-08-15 11:55:23,87084</td>
<td>OK</td>
</tr>
<tr>
<td>SHT</td>
<td>102</td>
<td>34.65  °C</td>
<td>37.9</td>
<td>2015-08-15 11:42:59,14927</td>
<td>OK</td>
</tr>
</tbody>
</table>

Example single modality diagram

Continuous multimodal sensor data visualization on overlapping coordinate systems (3 axis acceleration /x-blue, y-green, z-red/) with time

Complex data visualization (location activity and temperature)

PROBLEM with multi-modal data visualization!
HM-space visualization

Modified radar plot: dodecagon (a twelve-sided polygon or 12-gon)

- 11 sides (sectors) of the polygon are dedicated to the main human organ systems.

- 12th sector kept for visualization of external environment and derived data.

<table>
<thead>
<tr>
<th>Numbering</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sector I.</td>
<td>Integumentary</td>
</tr>
<tr>
<td>Sector II.</td>
<td>Muscular</td>
</tr>
<tr>
<td>Sector III.</td>
<td>Skeletal</td>
</tr>
<tr>
<td>Sector IV.</td>
<td>Nervous</td>
</tr>
<tr>
<td>Sector V.</td>
<td>Circulatory</td>
</tr>
<tr>
<td>Sector VI.</td>
<td>Endocrine</td>
</tr>
<tr>
<td>Sector VII.</td>
<td>Respiratory</td>
</tr>
<tr>
<td>Sector VIII.</td>
<td>Lymphatic / Immune system</td>
</tr>
<tr>
<td>Sector IX.</td>
<td>Urinary/excretory</td>
</tr>
<tr>
<td>Sector X.</td>
<td>Reproductive</td>
</tr>
<tr>
<td>Sector XI.</td>
<td>Digestive</td>
</tr>
<tr>
<td>Sector XII.</td>
<td>External and derived parameters</td>
</tr>
</tbody>
</table>
Parameter and HM-space visualization
Dynamic population health state model in HM-space

The average health status of the population \((S_{AVG}^*)\) can be defined as:

\[
S_{AVG}^* = \frac{\sum_{j=1}^{Q^*} S_j}{Q^*}
\]

where \(Q\) is the size of the targeted population and \(S_j\) is the health state of an individual from the population.

Population level HM-space

\[
HM_{j^*} = \frac{\sum_{j=1}^{P^*} HM_j}{p^*} = \frac{\sum_{j=1}^{P^*} (\Sigma_{i=1}^{NK} S_i w_i)}{p^*}
\]

\(\Sigma_{i=1}^{NK} w_i = 1\)
Population health state model visualization
Health state structure of the population

Visualize health parameters at population scale

- **Health pyramid**: Graphical illustration that shows the distribution of health state of various age groups in a population.

- **Health status vs. geolocation**: Can be used to determine the overall health state distribution of a population.
Conclusions

• eHealth and mHealth
  – can provide better services in optimized way
  – their definitions should vary at country level

• Realisation of eHealth requires plans, efforts, and resources

• If we can measure \(\Rightarrow\) we can evaluate!

• Health assessment is a challenging task
  – Human health state model
  – Population health state model

• Measure patient remotely \(\Rightarrow\) collect data \(\Rightarrow\) evaluate data
Conclusions (contd.)

• Implementing eHealth/mHealth strategies is difficult, and poses many questions
• There are good examples, case studies, services and solutions in Europe, in Asia, and in the US
• A possibility to leapfrog instead to re-inventing the wheel → facilitate knowledge and technology transfer
  – Faster implementation
  – Skip a lot of technology dead ends
  – Easier adaptation to local needs
Thank you for your attention...

Questions?

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