Remote monitoring of vital signs in patients with chronic heart failure

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Outline

• Introduction and motivations

• Sensing devices

• Sensor data signal processing

• Conclusions
Chronic heart failure

- CHF is a complex cardiovascular syndrome with progressive evolution
  - Several hospitalizations
- Main cause of hospitalization over 65 year
- UE Prevalence: around 15 millions
- UE Incidence: 3,600,000 new cases/year
Current Healthcare model

- Monitoring of vital signs during periodic visits
  - Poor ability to early detect the signs of destabilization
  - High number of re-hospitalization (45% are readmitted in hospital in the following 6 months)

- Consequences
  - Congestion in specialized center
  - Worsening patient’s quality of life
  - High healthcare costs
• Remote (home) monitoring is an effective and cost efficient healthcare service in CHF
  ✓ Allowing a daily collection and analysis of vital signs
  ✓ Reducing acting time in case of destabilization
  ✓ Reducing hospitalizations and costs
  ✓ Improving patient’s quality of life
The European Health@Home project

Wearable Wireless Sensors

Home Gateway

Software Platform

www.health-at-home-eu
Sensing Devices
Sensors Requirements

- Wearability / portability
- Non Invasivity
- Wireless communication
- Battery duration
- Initiator of connections towards the gateway
- Signal quality not excessively dependent on transducer positioning
- Basic and advanced arrangements

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Sampling</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 lead ECG</td>
<td>500 S/s/lead (12bit/S)</td>
</tr>
<tr>
<td>SpO2</td>
<td>3 S/s (10 bit/S)</td>
</tr>
<tr>
<td>Blood pressure</td>
<td>1 S/type (32bit int)</td>
</tr>
<tr>
<td>Weight</td>
<td>1 S (32bit float)</td>
</tr>
<tr>
<td>Chest imp.</td>
<td>25 S/s (10 bit/S)</td>
</tr>
<tr>
<td>Respiration</td>
<td>25 S/s (10 bit/S)</td>
</tr>
<tr>
<td>3 axes Posture</td>
<td>1 S/s/axis (8 bit/S)</td>
</tr>
</tbody>
</table>
• Bluetooth 2.0 (BT) short range protocol
  • Service Discovery Protocol (SDP)
  • Serial Port Profile (SPP)
• Initiator of point-to-point connections
  • Simply measurement process
• Bluetooth pros:
  • Adequate datarate (20kbps required)
  • Optional Authentication and Encryption
  • Wide diffusion with respect to Zigbee
Basic version of the system

- Digital scale
- Arm cuff Blood Pressure monitor
- ECG-SpO2 integrated module
  - Reducing the number of devices in the final system
  - Acquisition of synchronized ECG and SpO2 traces
ECG-SpO2 Module

- Ad-hoc developed for the H@H project
- Electrocardiographic signal
  - 4 leadwires: LA, LL, RA, RL (neutral)
- O2 Saturation and Plethysmographic signals
  - Fingerclip
- 92 x 150 x 28 mm
- Output:
  - 2 leads ECG, 500S/s
  - SpO2 3S/s
  - Plethysmographic wave 100 S/s
  - Diagnostic information
ECG-SpO2 Module Schematic

- 8 input differential ECG channels for signal conditioning of 3, 5, 12 leads
- Temperature and Pressure channels
- 12 bit resolution ADC @ 83KS/s
- PaceMaker detector, 50Hz filter
- Serial Communication Interface
- CMOS technology 14 x 14 x 1.4 mm

- 16-Bit RISC Arch.
- 4 USCIs
- Power 1.8 to 3.6 V
- 12 bit A/D, D/A

Li-Ion battery
3.7 V 1700 mAh

- Oxigen saturation @ 3Hz in [45% - 100%]
- Plethysmographic wave @ 100Hz in [0 - 255]
- UART-TTL Interface
- 31 x 14 x 5 mm

- BT 2.0 SDP / SPP
- Class I (< 27 db)
- Serial Interface
- Phillips BGB203
- Onchip memory
CARDIC Chip Schematic
Blood pressure monitor & Digital scale

- UA-767BT by A&D Medical
  - SYS and DIA values
  - Sensibility range: 20-280 mmHg
  - Accuracy: +/- 3 mmHg
  - 147 x 110 x 64 mm
  - 4 AA Batteries

- UA-321PBT by A&D Medical
  - Weight value only
  - Maximum capacity: 200 Kg
  - Accuracy: +/- 0.1 Kg
  - 300 x 300 x 30 mm
  - 4 AA Batteries
Signal Processing
Signal Processing chain

- Fundamental role to early detect alterations
- Real-time execution on the home gateway

- Pre-processing
  - Recognition of valid measures
  - Filtering noises and gathering derived information

- Analysis
  - Checking if values and trends lay within the safe zone

- False positive avoidance
  - Alarm is sent if a deferred measure (minutes) confirms the result
ECG – Signal processing

normalized signal decomposition

raw ECG
kaiser filtered ECG
differenced signal
squared signal
averaged signal

QRS threshold
ECG – R peaks detection

- Comparing the averaged signal against a threshold creates a set of windows where the R peaks can be located.
- The maximum positive peak of the filtered signal within the windowed signal will be considered the R peak.
- R peak has still to pass through a rule based system that evaluates whether the detected QRS is a valid:
  - Distance in time between consecutive peaks (if < refractory period of the myocardium (200ms) one is discarded)
  - T-wave discrimination by being stricter about those peaks situated 200 – 360ms later than an accepted peak
  - Check for possible missed peaks when the current RR interval is 1.5 times the previous RR interval
- C implementation (VSIPL Library)
Heart Rate calculation

- Heart Rate is calculated using a 30 seconds window that is shifted along the time axis on 5 seconds length steps.

- For each step, the number of beats within the window is counted and that value is extrapolated to a 60 seconds window to get the value in beats per minute.

- Maximum, minimum and average rates along the track are calculated and analyzed.
ECG – Filtering and R-wave

![ECG Waveforms]

- **Raw ECG**
- **Filtered ECG**
- **R Peaks**
- **R Peaks Envelope**

*Graph showing raw, filtered ECG signals with identified R-peaks and envelope.*
Oxygen saturation

- Oxygenation can quickly change in CHF
  - Frequent monitoring avoids these changes to go undetected
- Maximum, minimum and average value over the track (extracted by a low-pass FIR filter)
  - Single value threshold comparison
  - Trend extraction of average value
• Abnormality of punctual values and variability in short periods are CHF manifestations

• Systolic and Diastolic values
  – Upper and lower bounds thresholds for single values
  – Trends extraction
Weight – Signal Processing

- Very easy to measure and effective in CHF
- A rapid gain due to fluid retention, +1Kg/Day or +3Kg/Week is considered dangerous
  - Trends extraction
- Avoidance of measures that differ more than 3Kg from the last one
Results and Conclusions
Technical validation results

- 30 patients, 1 month of monitoring
- Activity miss < 2%
- False positive alarms <5%

<table>
<thead>
<tr>
<th>Macro-parameter</th>
<th>SCORE</th>
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</thead>
<tbody>
<tr>
<td>Simply decision and increase effectiveness of diagnosis and treatment of patient based on better evidence</td>
<td>9,1 / 10</td>
</tr>
<tr>
<td>In general terms, easy to use with clear and understandable interactions</td>
<td>9,5 / 10</td>
</tr>
<tr>
<td>Flexibility of the system and compatibility with other systems already in use</td>
<td>9,75 / 10</td>
</tr>
<tr>
<td>Quality of the provided signal</td>
<td>9,1 / 10</td>
</tr>
<tr>
<td>Sensibility of the alarm detection function</td>
<td>9,15 / 10</td>
</tr>
<tr>
<td>In favor of the adoption of the H@H system</td>
<td>9,2 / 10</td>
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</table>
Conclusions

• The H@H system allows medical staff to monitor their patients at distance
  – Improvements in healthcare service provisioning

• The basic kit includes synchronized ECG-SpO2, Weight and Blood Pressure
  – Real-time processing at home

• Future work:
  – Additional sensing devices
  – Multi-sensors data fusion
  – Clinical validation with 500 patients