Remote monitoring of vital signs in patients with chronic heart failure

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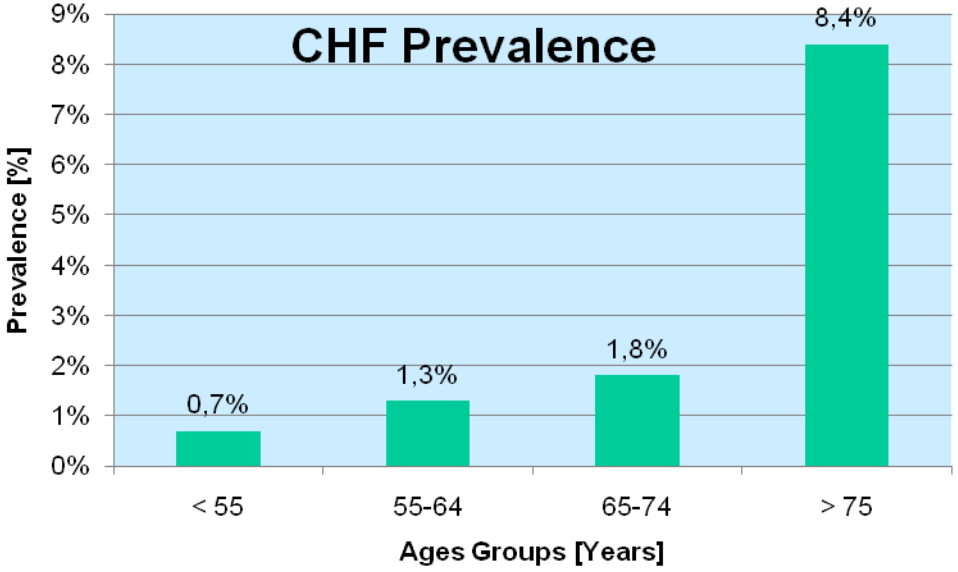
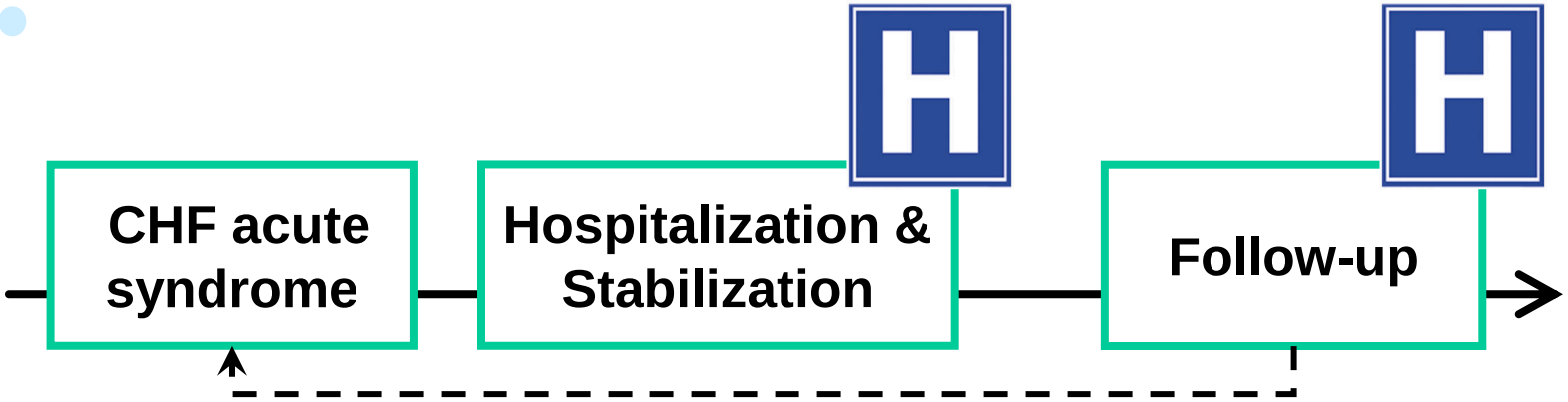
Outline

- Introduction and motivations
- Sensing devices
- Sensor data signal processing
- Conclusions

- 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

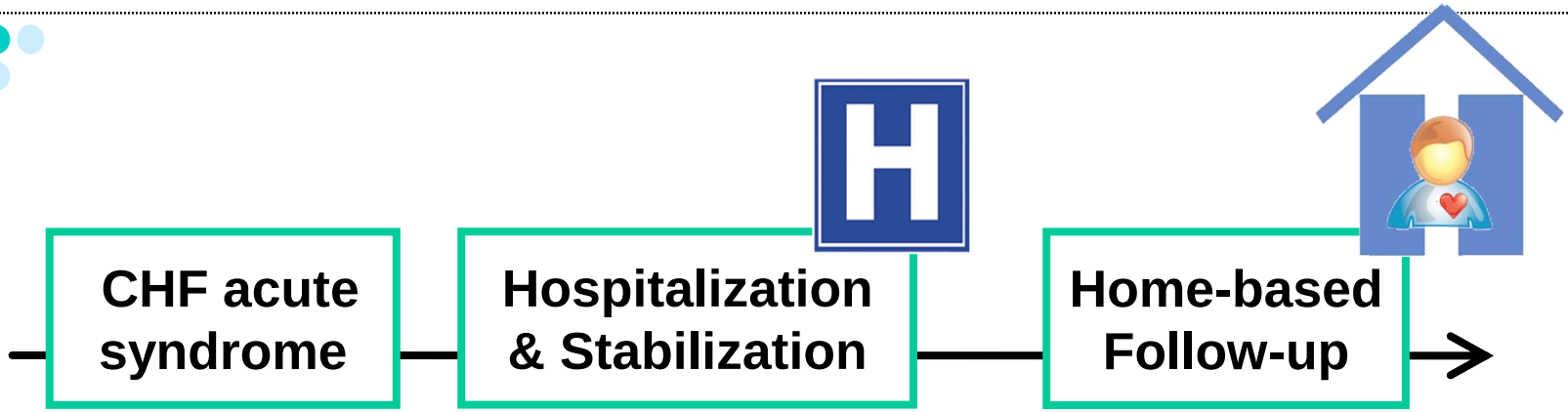


Current Healthcare model



- 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

Telemonitoring in CHF patient



- 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

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

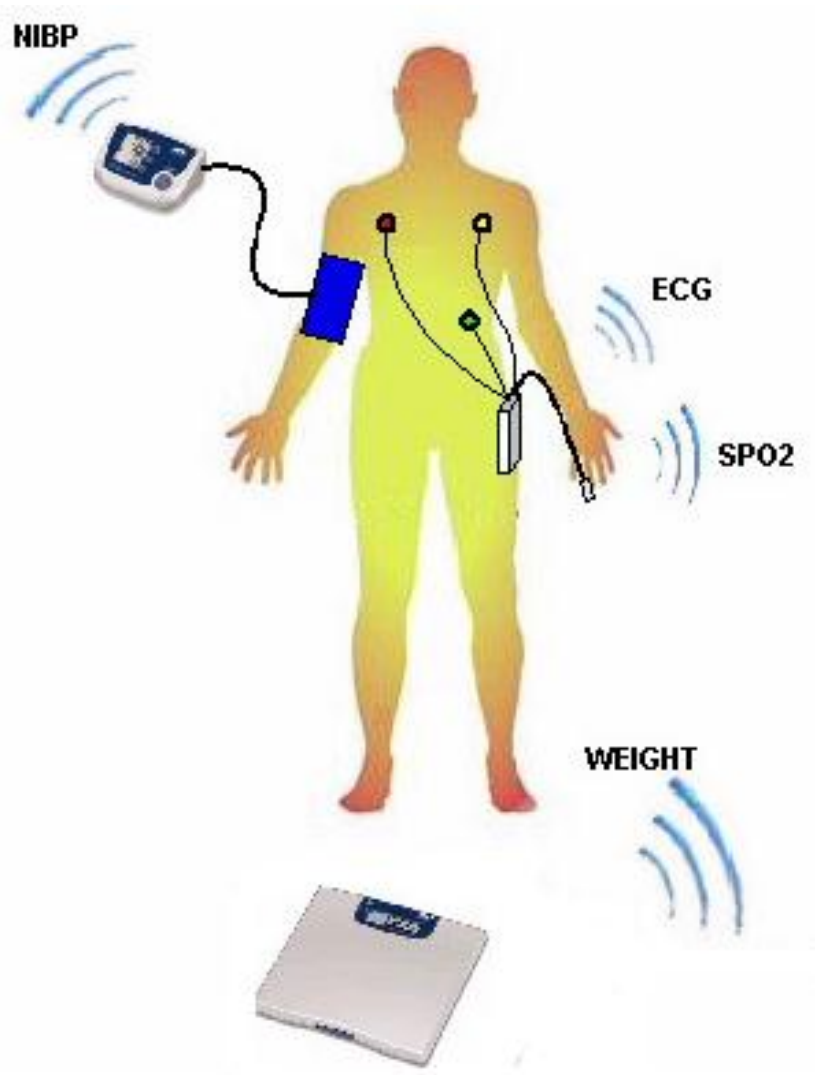
Parameter	Sampling
3 lead ECG	500 S/s/lead (12bit/S)
SpO2	3 S/s (10 bit/S)
Blood pressure	1 S/type (32bit int)
Weight	1 S (32bit float)
Chest imp.	25 S/s (10 bit/S)
Respiration	25 S/s (10 bit/S)
3 axes Posture	1 S/s/axis (8 bit/S)

Sensors Communication Scheme

- 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

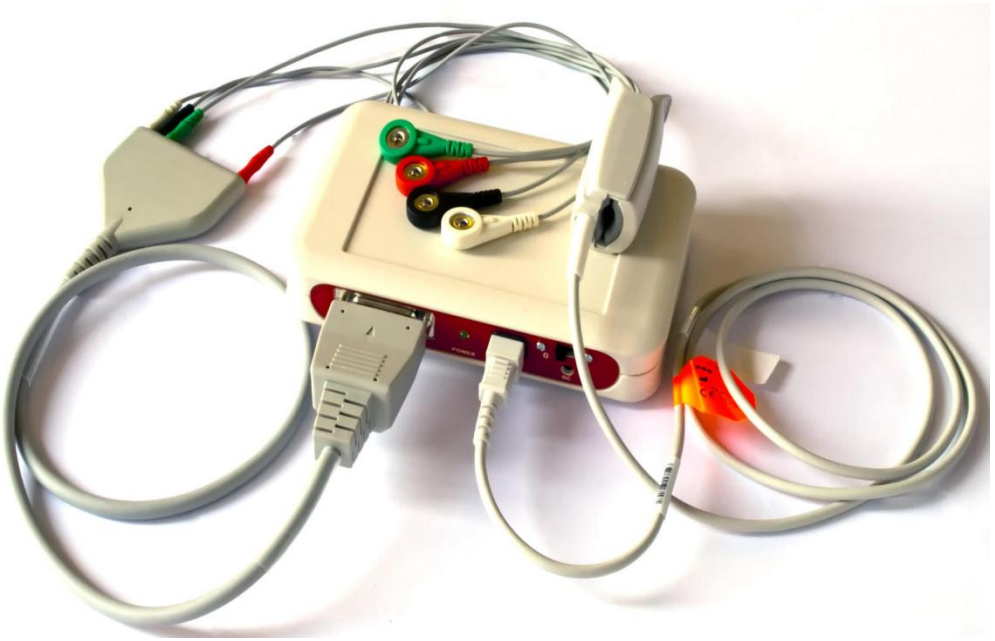
Basic version of the system

- 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

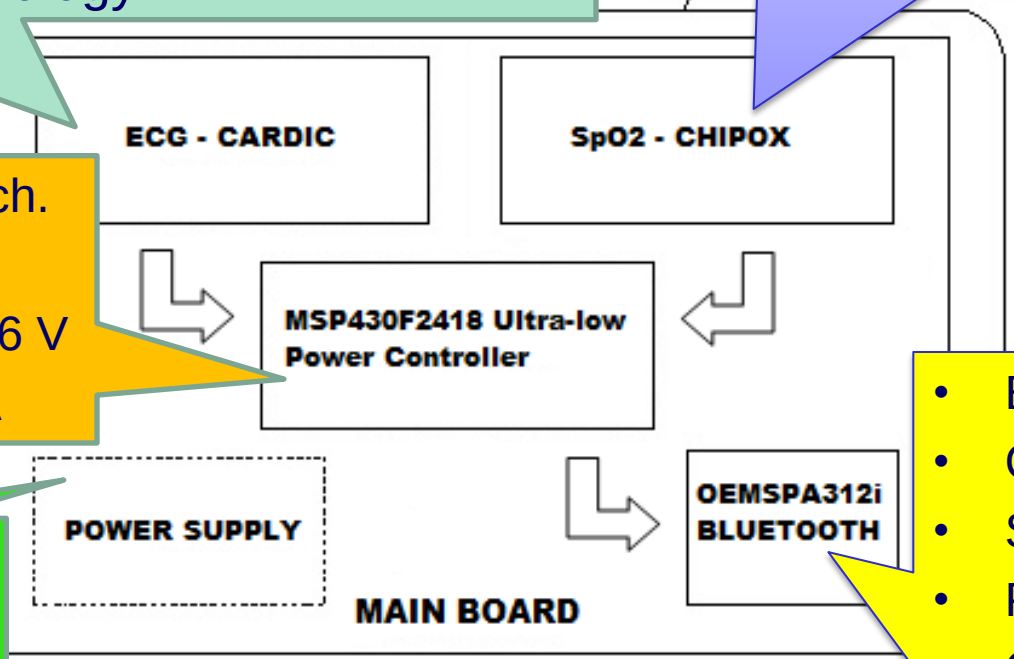
- Ad-hoc developed for the H@H project
- Electrocardiographic signal
  - 4 leadwires: LA, LL, RA, RL (neutral)
- O2 Saturation and Plethismographic signals
  - Fingerclip
- 92 x 150 x 28 mm
- Output:
  - 2 leads ECG, 500S/s
  - SpO2 3S/s
  - Plethysmographic wave 100 S/s
  - Diagnostic information



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

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

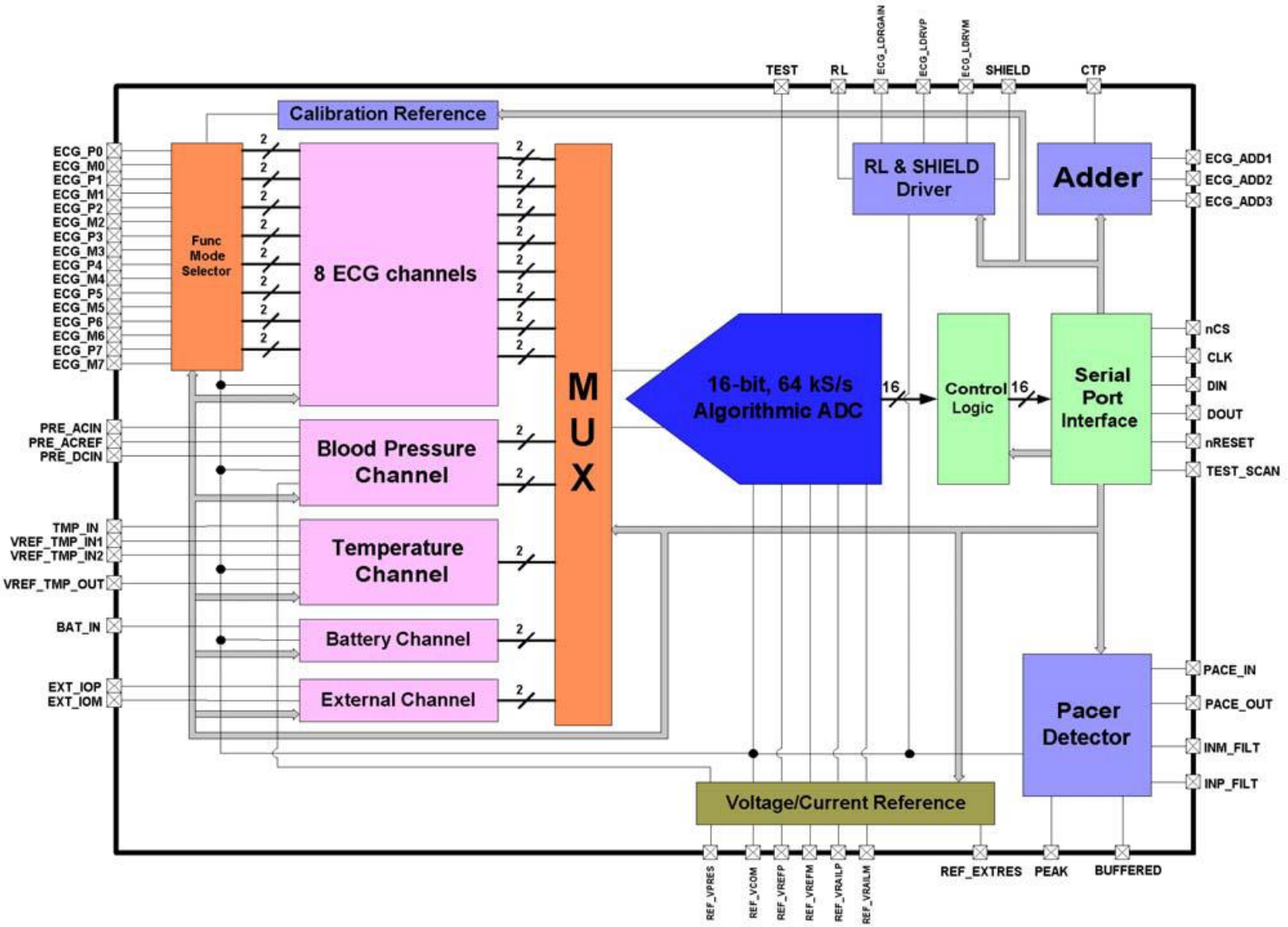


- 16-Bit RISC Arch.
- 4 USCIs
- Power 1,8 to 3,6 V
- 12 bit A/D, D/A

Li-Ion battery
3.7 V 1700 mAh

- BT 2.0 SDP / SPP
- Class I (< 27 db)
- Serial Interface
- Phillips BGB203
- Onchip memory

CARDIC Chip Schematic



Blood pressure monitor & Digital scale

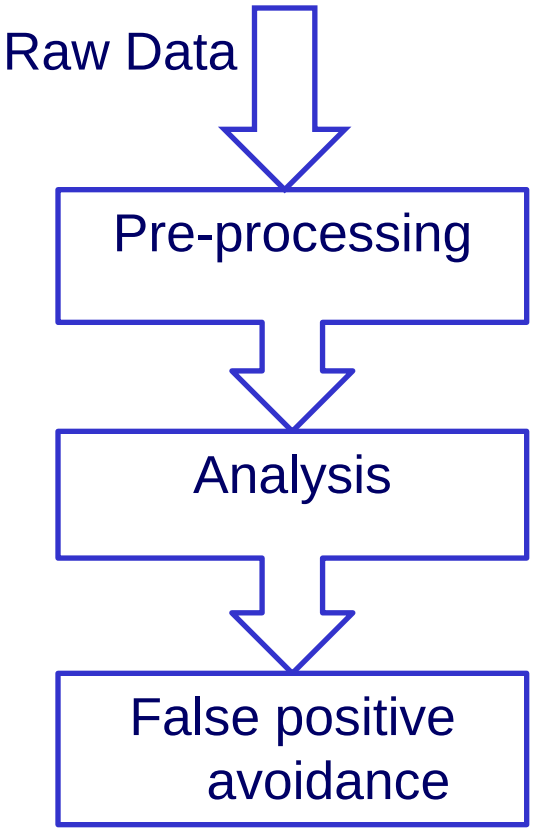
- UA-767BT by A&D Medical
- SYS and DIA values
- Sensibility range: 20-280 mmHg
- Accuracy: +/- 3 mmHg
- 147 x 110 x 64 mm
- 4 AA Batteries

- 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

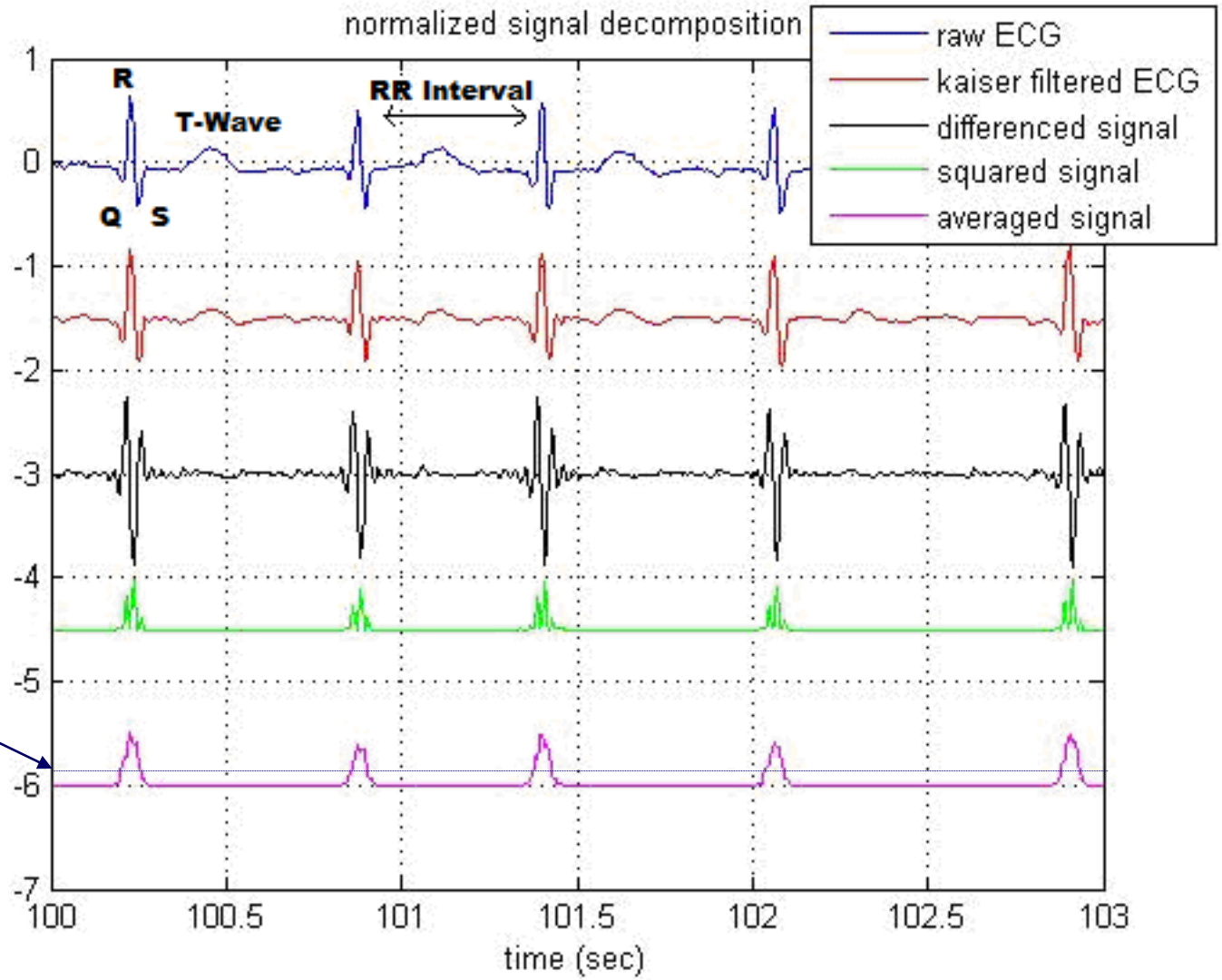
Signal Processing

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



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)

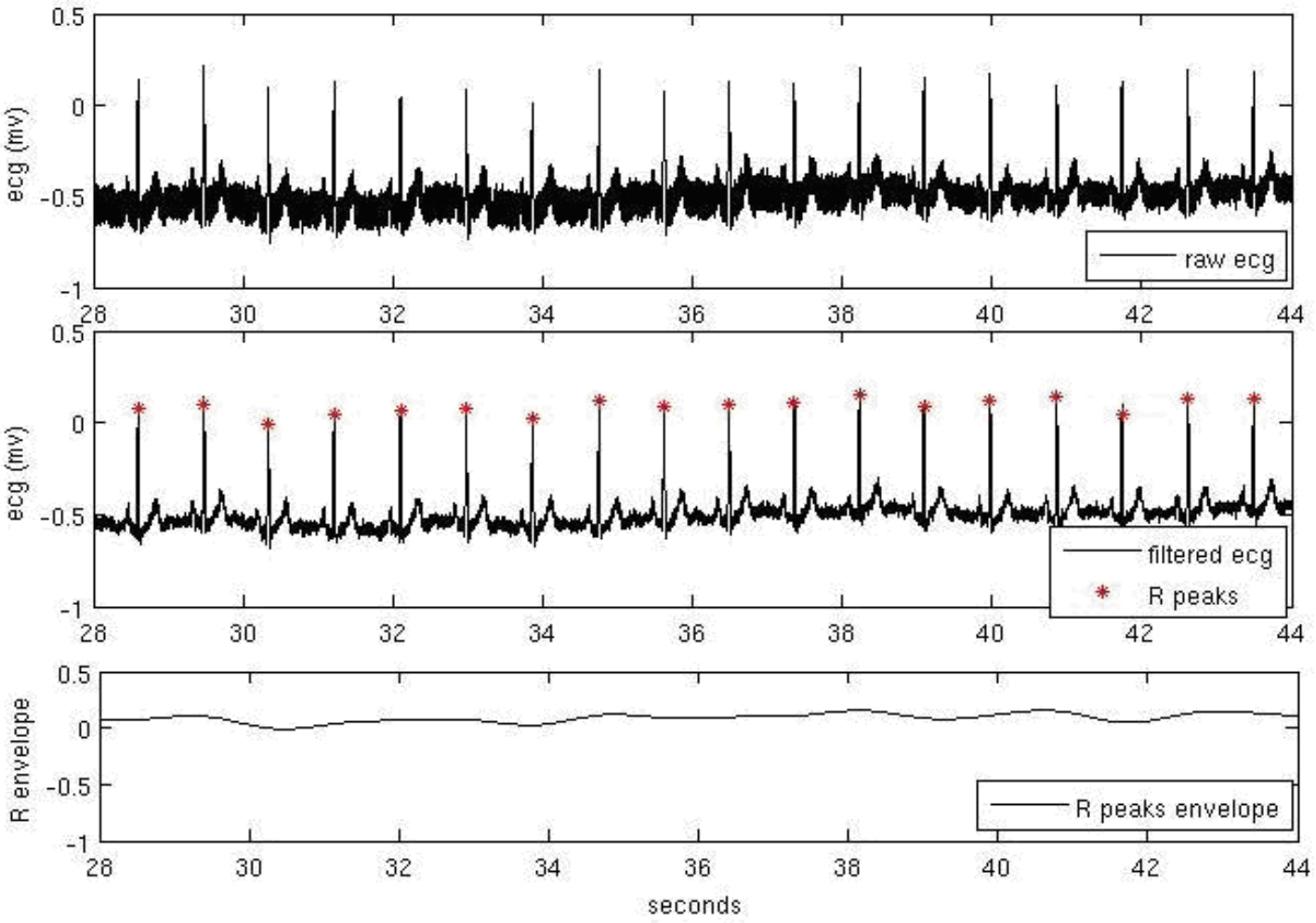
Heart Rate calculation

- 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.

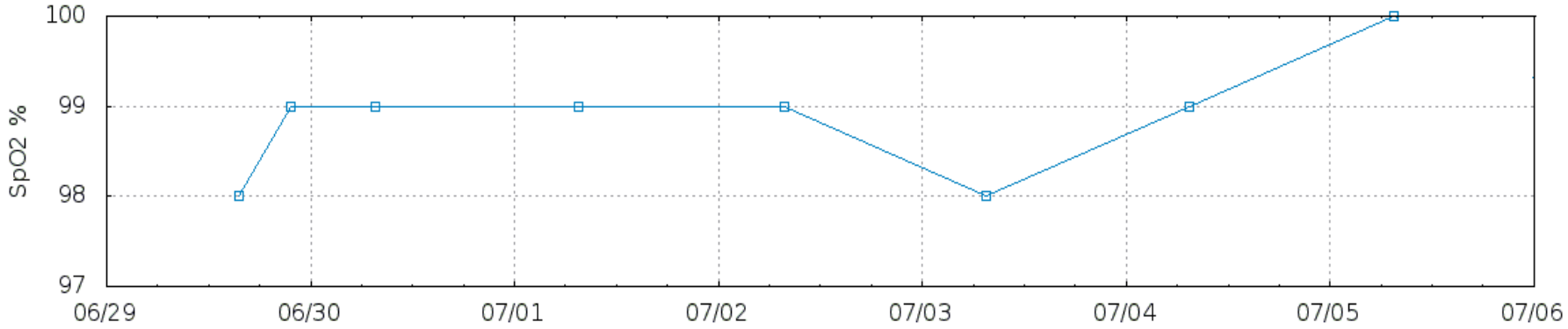
- Maximum, minimum and average rates along the track are calculated and analyzed.

ECG – Filtering and R-wave



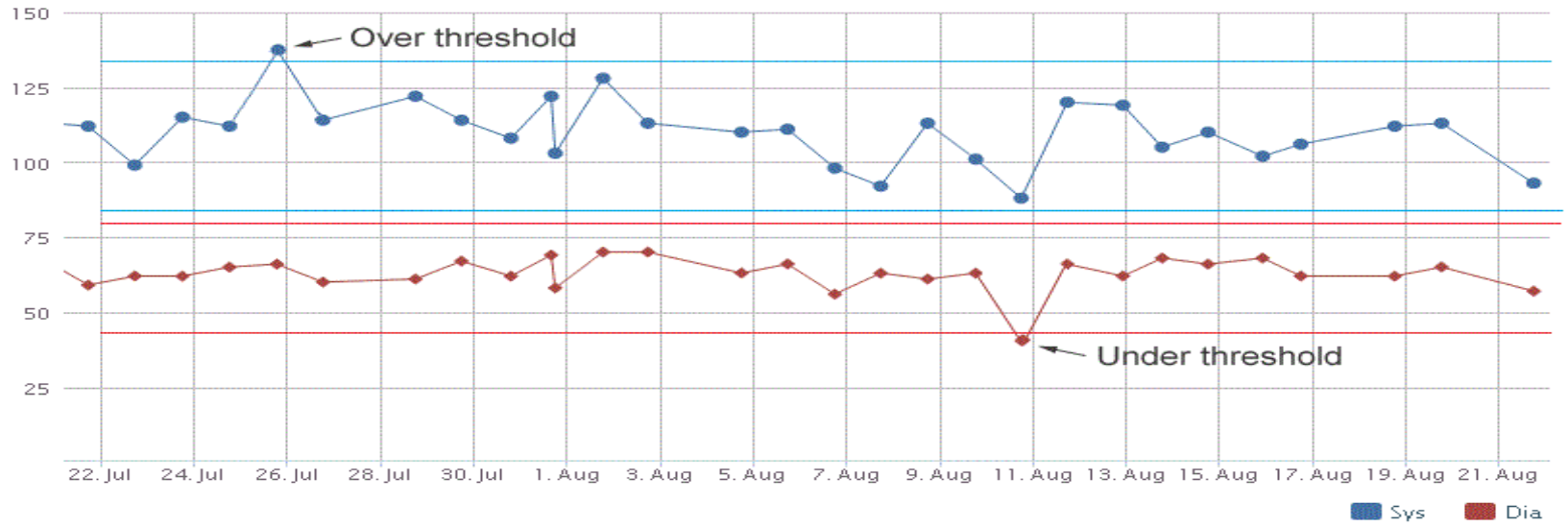
Oxigen saturation

- 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



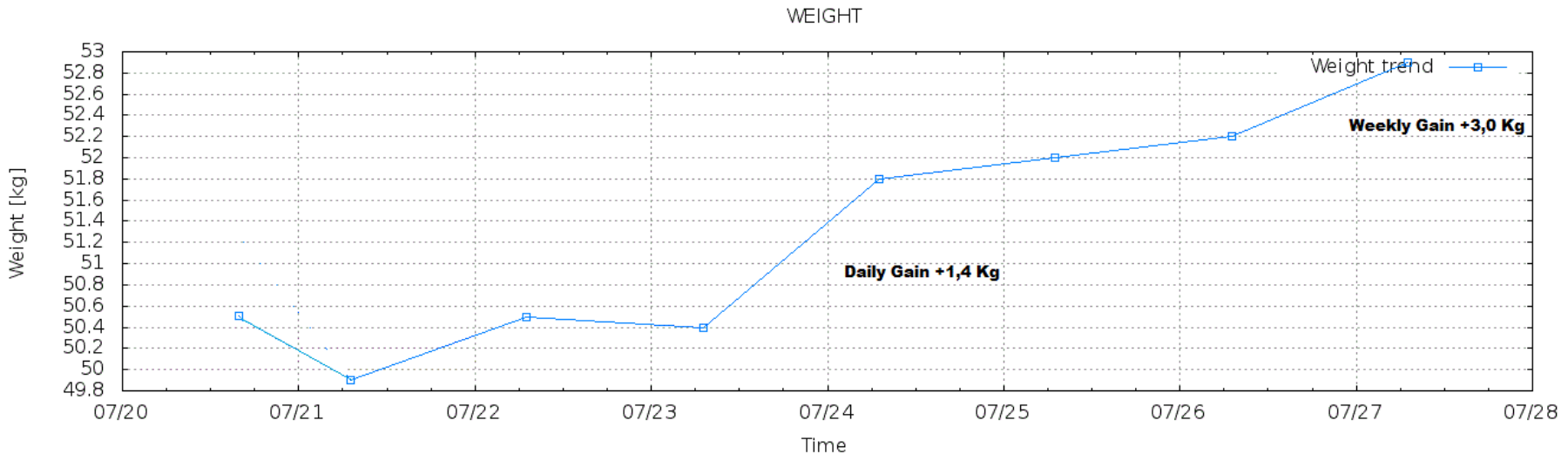
Blood Pressure – Signal Processing

- 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

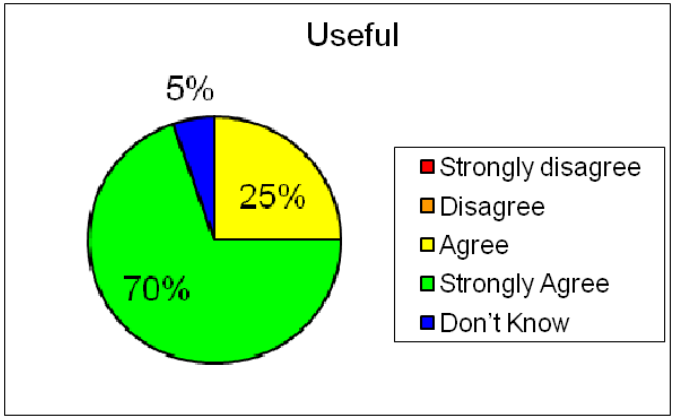


Results and Conclusions

Technical validation results

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

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



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