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Multimodal Unobtrusive Devices for Chronic Disease Monitoring

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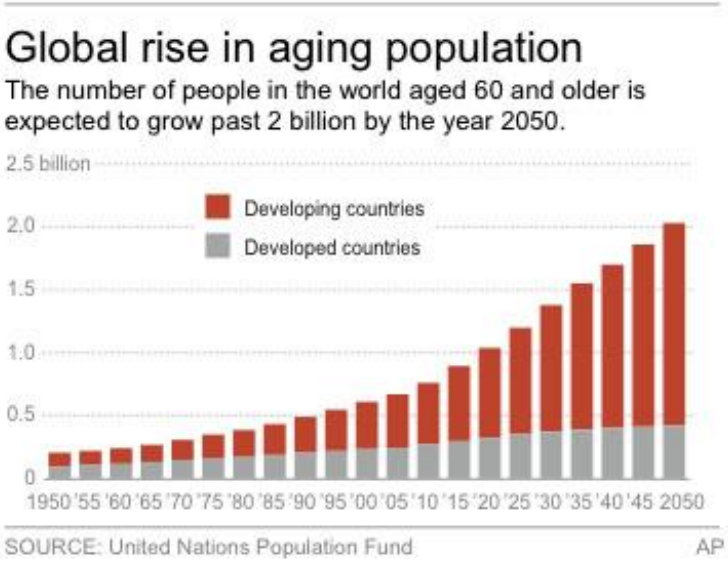
COST EMF-MED Workshop on Vagus Nerve Stimulation
Warsaw, 16 February 2017

Plan

- Motivation – chronic diseases
- Promises of vagus nerve stimullation in treatment of atrial fibrillation
- 2 devices – EU FP7 project “CARRE” partial results
  - Wrist-worn device for continuous monitoring
  - Multiparametric weight scales for intermittent monitoring
- Summary

Motivation: chronic diseases

- Aging of the population increases prevalence of chronic diseases
  - chronic kidney disease – 13 % over the world
  - atrial fibrillation (AF) – 2 % of general population & > 6% after 70 years of age
  - peripheral arterial disease (PAD) - 20 % over 70 years of age

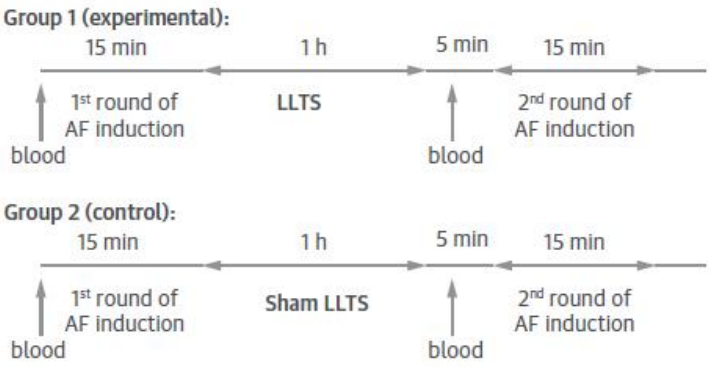


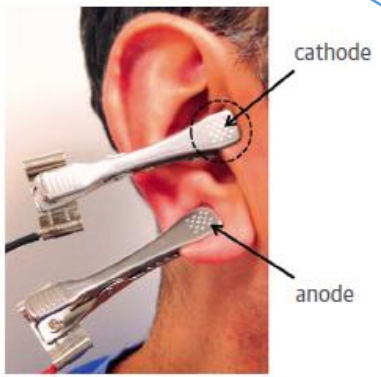
Motivation: a new kind of atrial fibrillation therapy

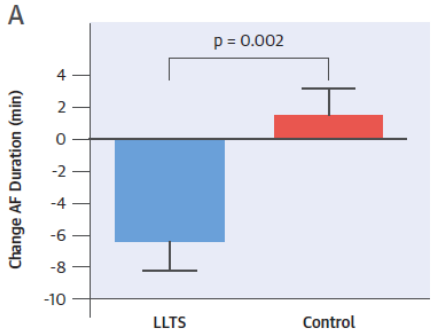
- Current therapy in AF patients - catheter ablation
- New kind of AF therapy - transcutaneous electrical stimulation of vagus nerve*

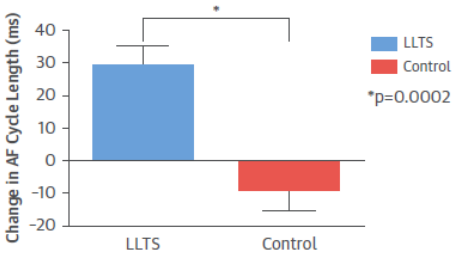
✓Results:

- VNS stimulation prolongs AF cycle length
- Reduces AF duration









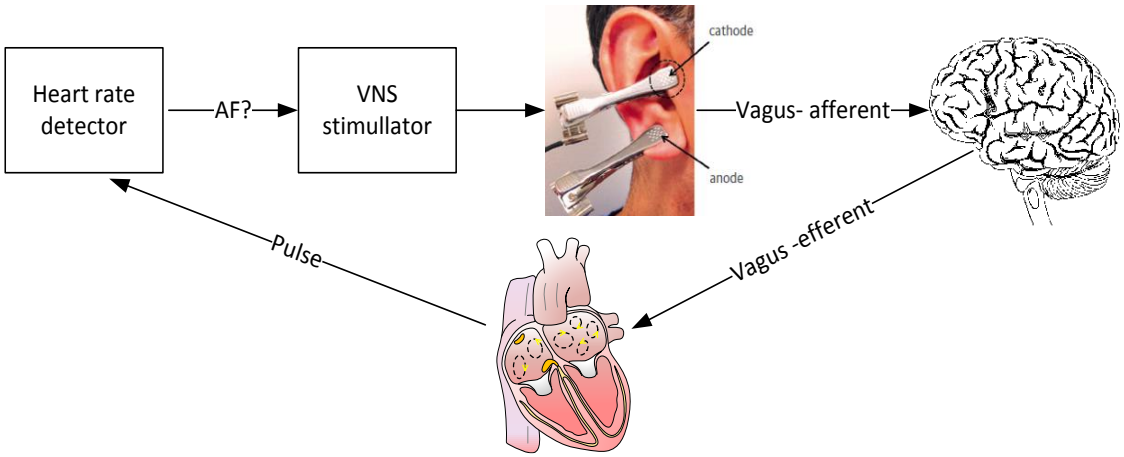
Stavrakis S., et. al. **Low-level transcutaneous electrical vagus nerve stimulation suppresses atrial fibrillation**. *J Am Coll Cardiol*. 2015 Mar 10;65(9):867-75.

A noninvasive approach to treat the initial phase of atrial fibrillation

- "Low-level tragus stimulation can reverse atrial remodeling and inhibit AF inducibility, suggesting a potential noninvasive treatment of AF"

Yu L, Scherlag BJ, Li S, et al. Low-level transcutaneous electrical stimulation of the auricular branch of the vagus nerve: a noninvasive approach to treat the initial phase of atrial fibrillation. Heart Rhythm 2013;10: 428–35.

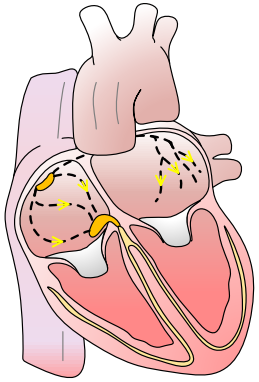
- Solution to prevent AF?



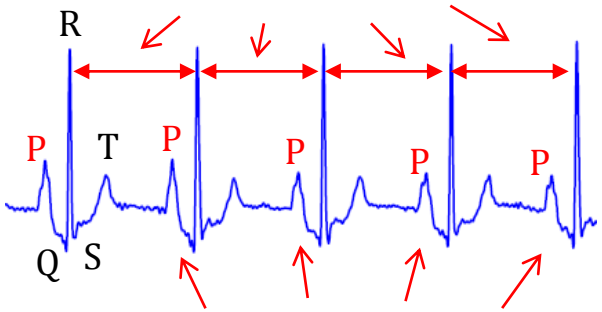
How to continuosly monitor AF in unobtrusive way?

Medical background – AF heart arrhytmia

Normal rhythm

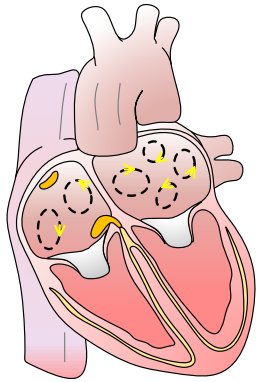


Regular ventricular contractions

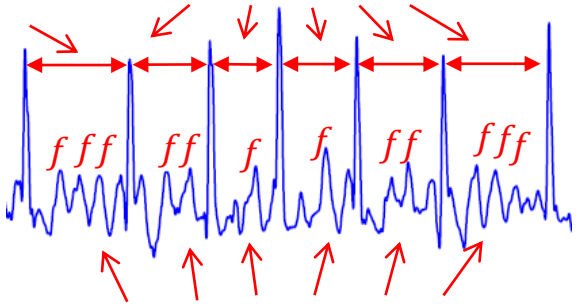


Regular atrial contractions (P waves)

Atrial fibrillation



Irregular ventricular contractions

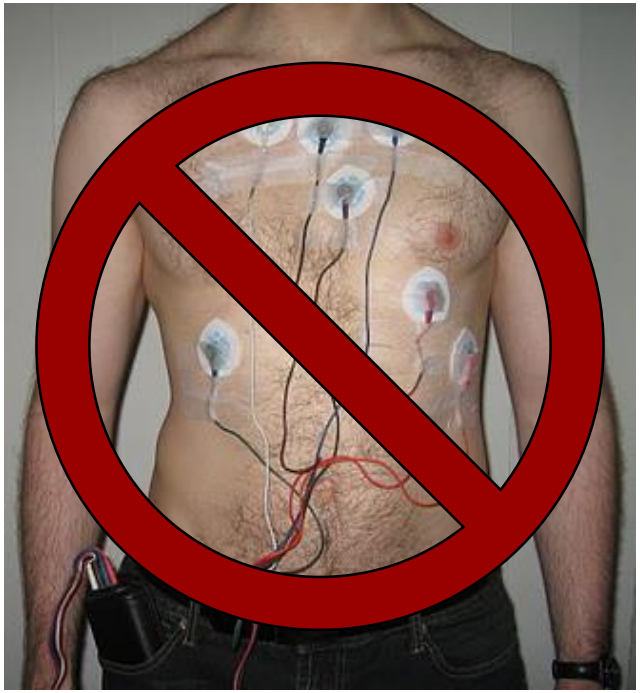


Continuous atrial activity (f waves)

AF detection

Only prolonged AF can be detected with standard 12-lead electrocardiogram (ECG).

Self-terminating paroxysmal AF is identified with 24-hour Holter monitoring.

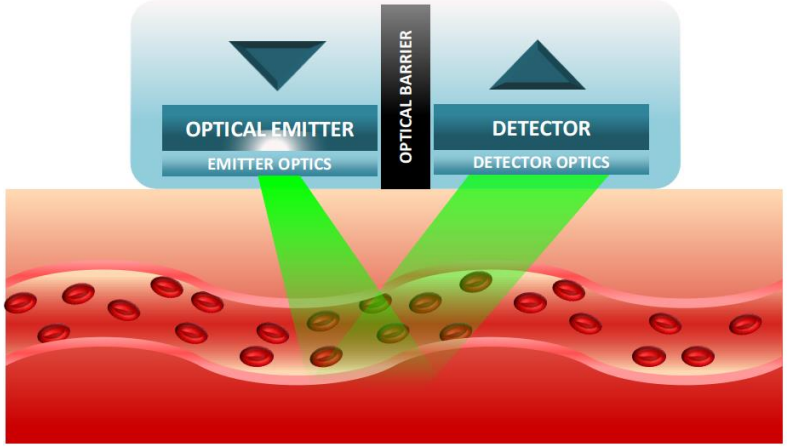


The major drawback is the adhesive electrodes (possible allergy) and the connecting wires (discomfort), eventually leading to premature termination of recording.

Calkins et al. 2012 HRS/EHRA/ECAS Expert Consensus Statement on Catheter and Surgical Ablation of Atrial Fibrillation. Journal of Interventional Cardiac Electrophysiology, 33(2), 2012. – p. 171-257.

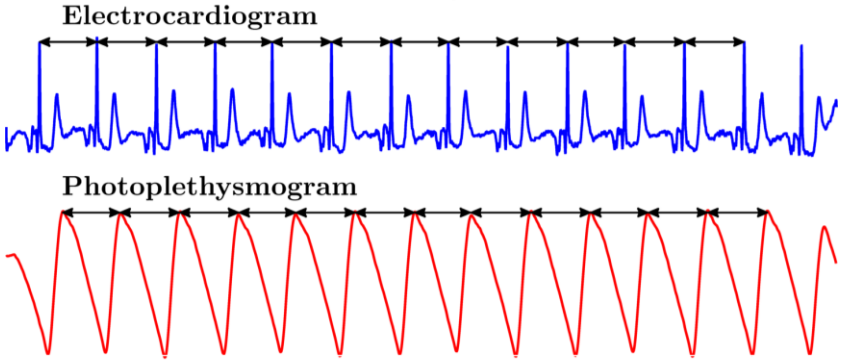
Solution for unobtrusive monitoring

Unobtrusive optical technology – photoplethysmography (PPG) – measures light absorption changes in the skin due to pulsatile blood flow.

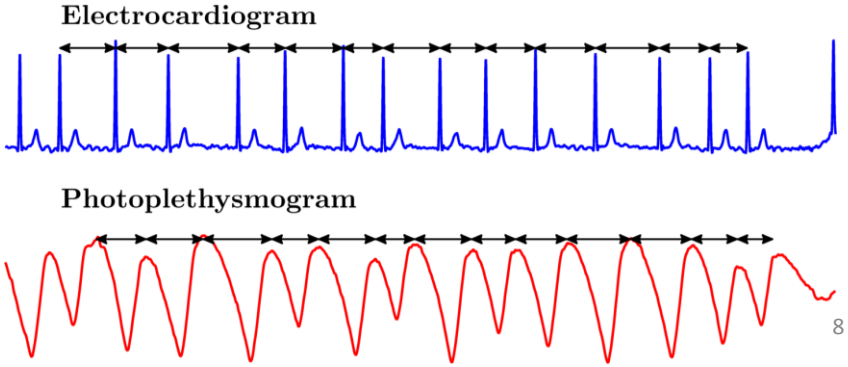


Similarly to ECG, the peaks in the PPG signal represent ventricular contractions, allowing to compose pulse-to-pulse (*PP*) interval series.

Sinus rhythm



Atrial fibrillation



Aim of the study

Preliminary studies showed that PPG technology is suitable for AF detection, employing the built-in camera of a smartphone.

Is PPG-based AF detection reliable in long-term monitoring?

The aim - to investigate the feasibility of long-term monitoring using wrist-worn device, capable of acquiring PPG.

Wrist worn device: hardware

- Sensors:
  - 4 ch. PPG
  - 1 lead ECG
  - 3 ch. accelerometer
  - altitude (for stairs climbing detection)
  - capacitive sensor for motion artefacts mitigation

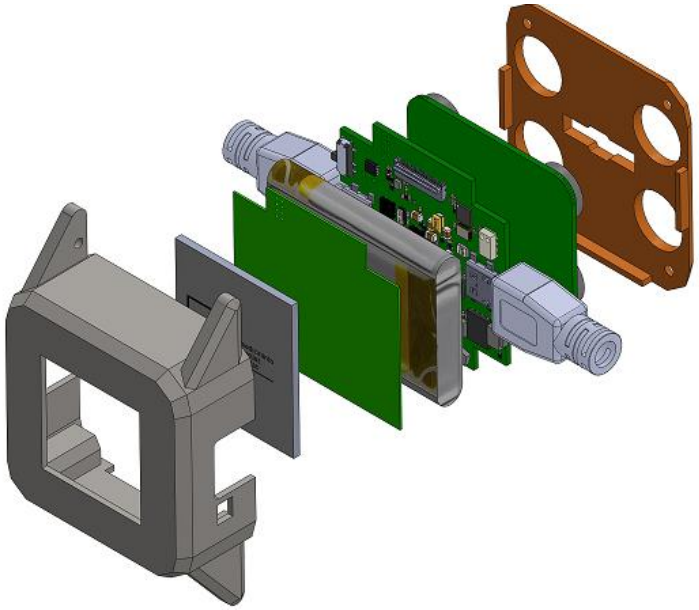
1st prototype 2nd prototype 3rd prototype

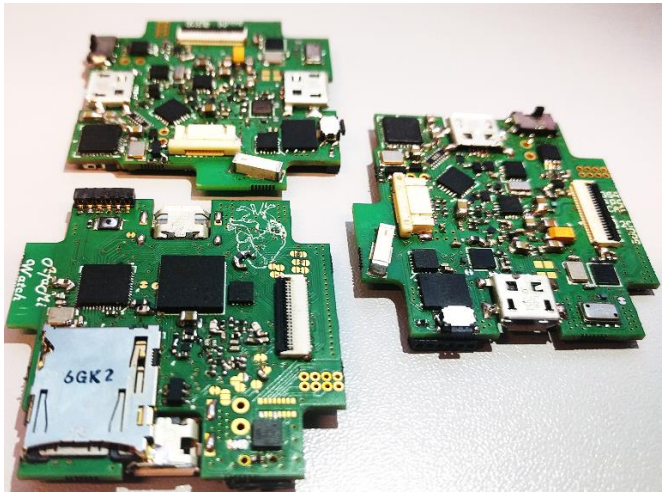


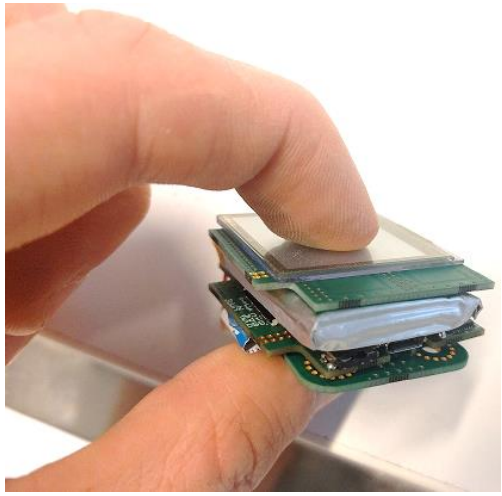
- Hardware:
  - main component - ARM Cortex-M4 µPr + BLE4.0 transiver in nRF52832

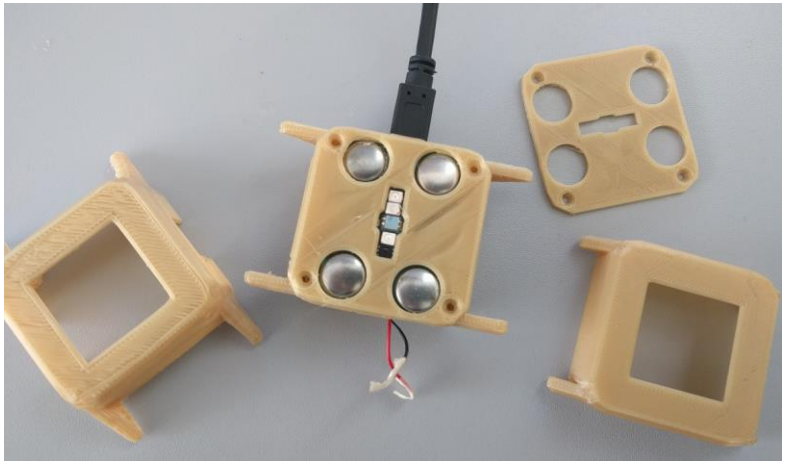
- Main functions:
  - scientific instrument for multimodal long term physiological data acquisition
  - algorithms for real-time and offline paroxysmal AF detection

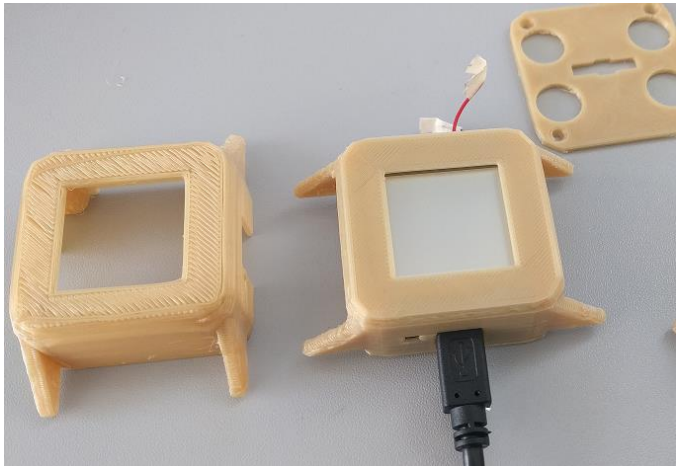
Wrist worn device: prototype v3



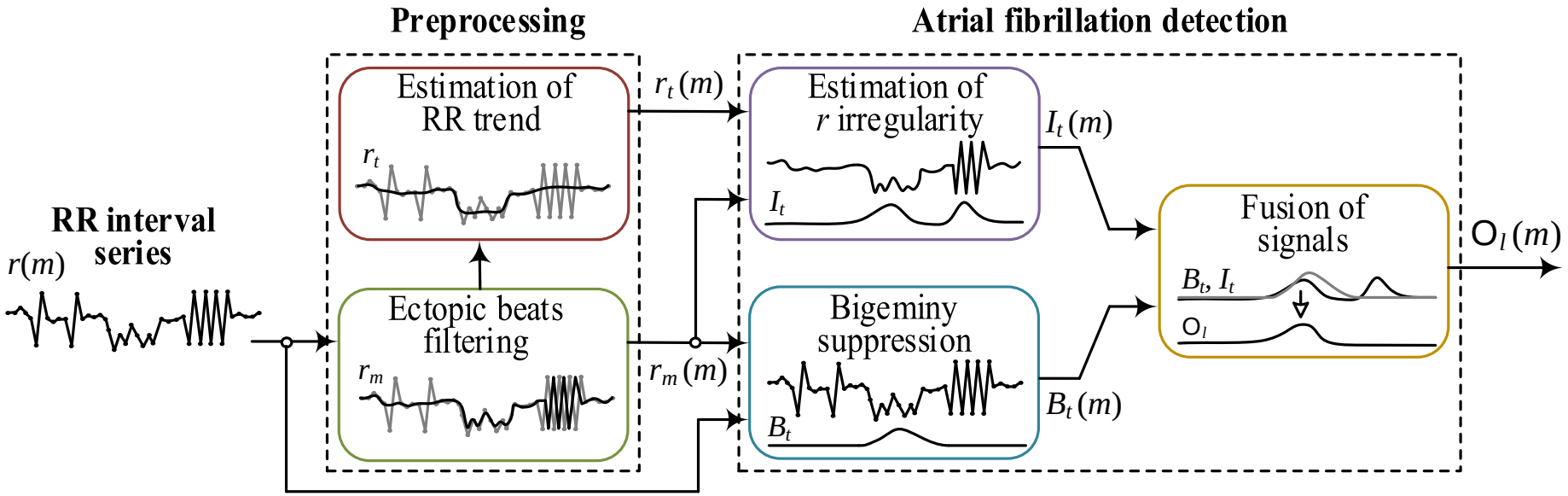








Entropy based AF detection algorithm*



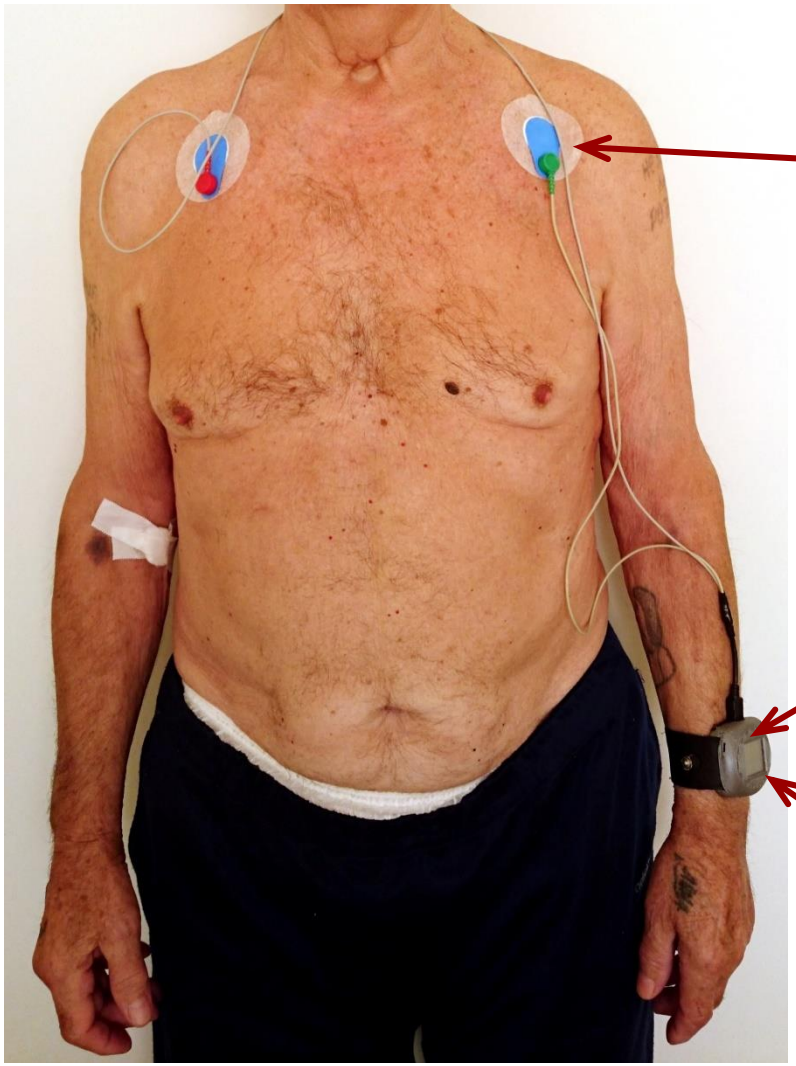
AF is detected in a sliding window of just **8 heart beats**

Due to low-complexity structure achieved, heart rhythm analysis-based algorithm for paroxysmal atrial fibrillation detection can be implemented in a low-power device for prolonged monitoring applications.

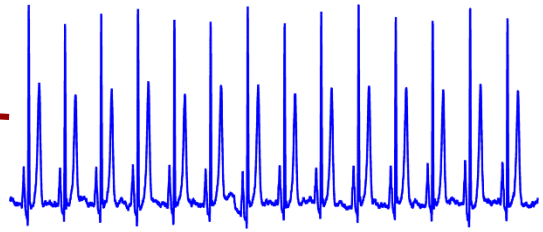
*Petrėnas, A. et. al., L. Low-complexity detection of atrial fibrillation in continuous long-term monitoring // Computers in biology and medicine. 2015, vol. 65, p. 184-191.

Can ECG-based algorithm be used for PPG-based AF detection?

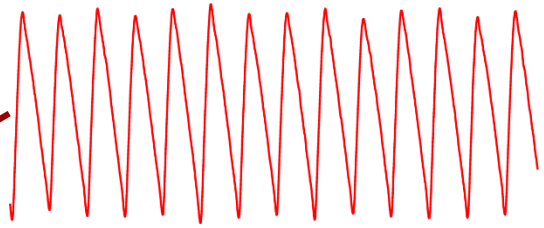
Wrist-worn device: signals



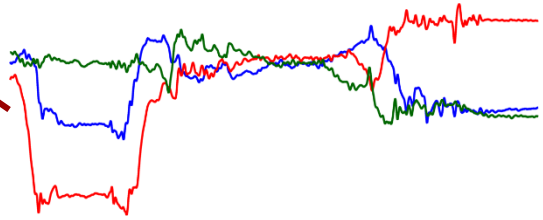
Reference signal – **electrocardiogram**



Signal under investigation – **photoplethysmogram**

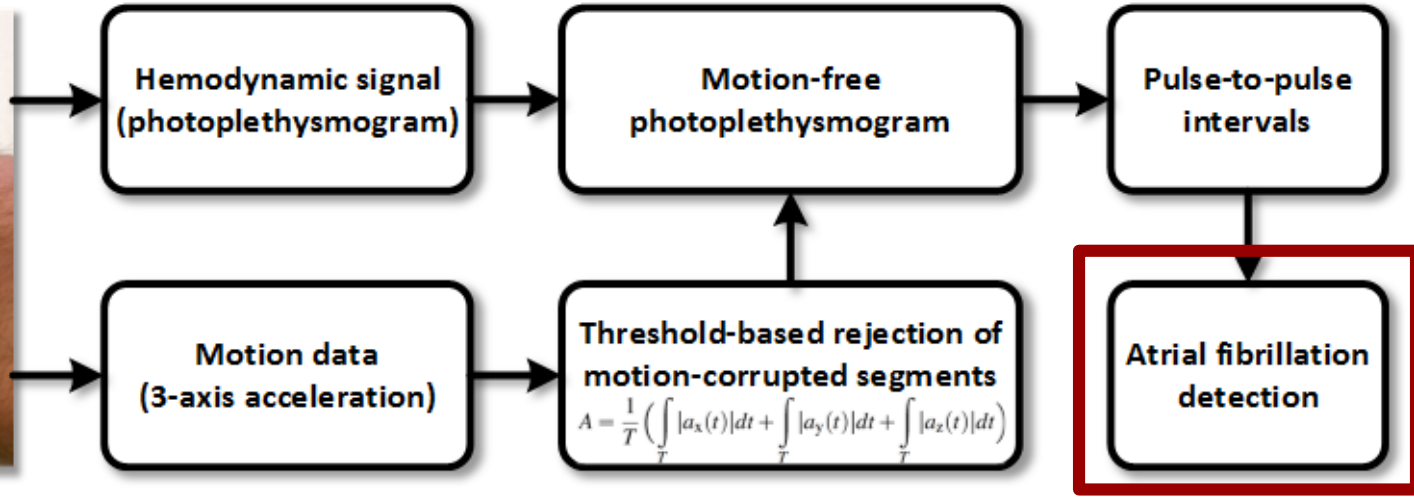


Motion corrupted episodes rejection based on **3-axis acceleration**



Wrist-worn device: operation

- Operation:
  - 3-axis accelerometer applied to identify motion
  - pulse-to-pulse (PP) intervals extraction from motion-free PPG
  - AF detection based on intervals irregularity



Study population and data

The study was approved by Kaunas Region Biomedical Research Ethics Committee (No. BE-2-20).

Study participants were involved at Kulautuva Rehabilitation Hospital of Kaunas Clinics, Lithuania.

Two groups of patients

6 with AF
71.8 ± 9.2 years old
21.3 ± 2.6 hours per patient

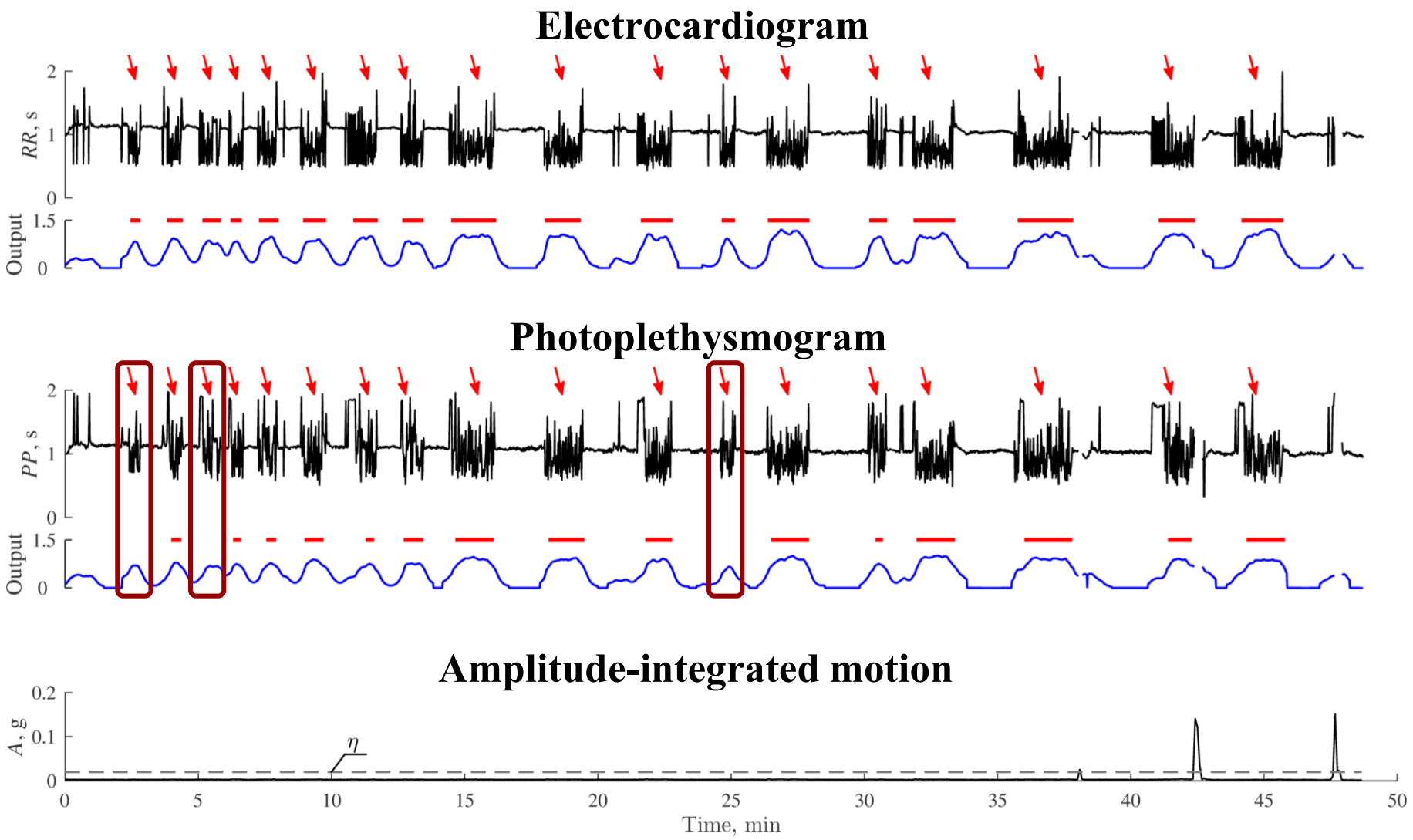
6 without AF
64.3 ± 9.4 years old
22.7 ± 2.8 hours per patient

This resulted in 86.8 hours of data with AF and 85.4 hours without AF.

Comparison of AF detectors evaluated on ECG and PPG

Methods	Electrocardiogram		Photoplethysmogram	
	***Sensitivity*, %**	***Specificity*, %**	***Sensitivity*, %**	***Specificity*, %**
Sarkar et al. (2008)	99.9	81.3	99.9	78.9
Dash et al. (2009)	100	64.3	100	66.2
Lake et al. (2011)	100	82.2	100	80.4
Petrėnas et al. (2015)	99.4	89.9	99.9	91.5

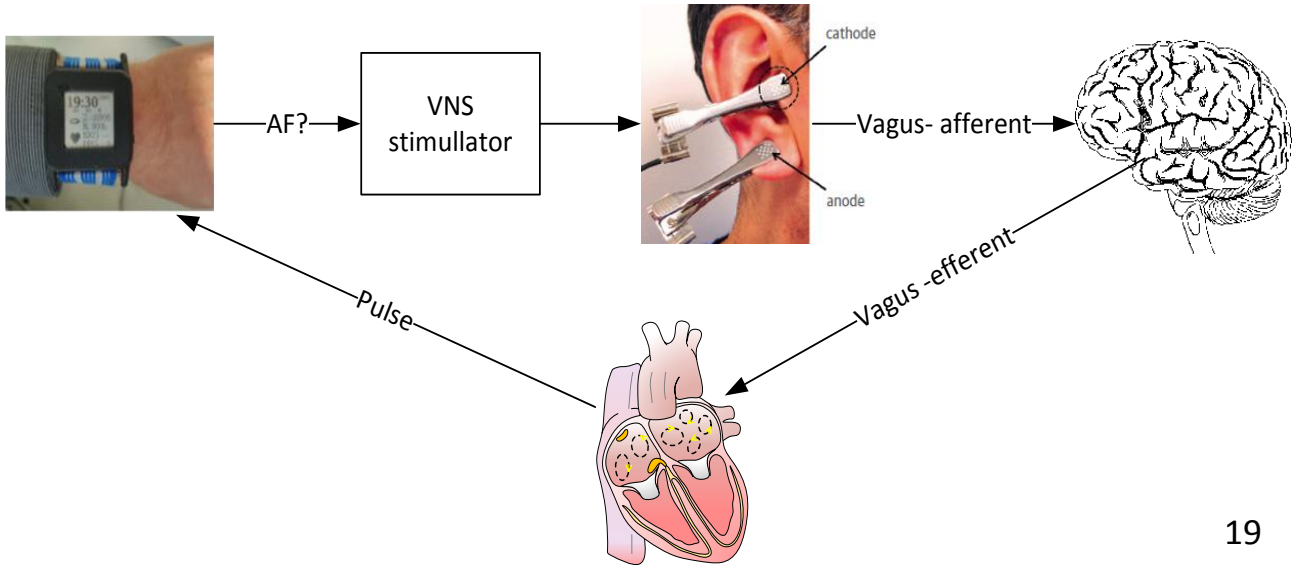
Detection of self-terminating AF



Wrist worn device in AF detection

- Results:
  - about **66%** of total recording time was motion-free and suitable for AF detection
  - sensitivity and specificity of PPG-based AF detector reached **99.9%** and **91.5%**
  - performance comparable to that obtained using ECG

- For discussion:



Multiparametric weight scales

Motivation

- Peripheral artery disease is associated with the increased arterial stiffness
- Arterial stiffness can be assessed by either pulse wave velocity or pulse arrival time (PAT)
- Operator dependence restricts periodic assessment of arterial stiffness in long-term self-monitoring by target patients

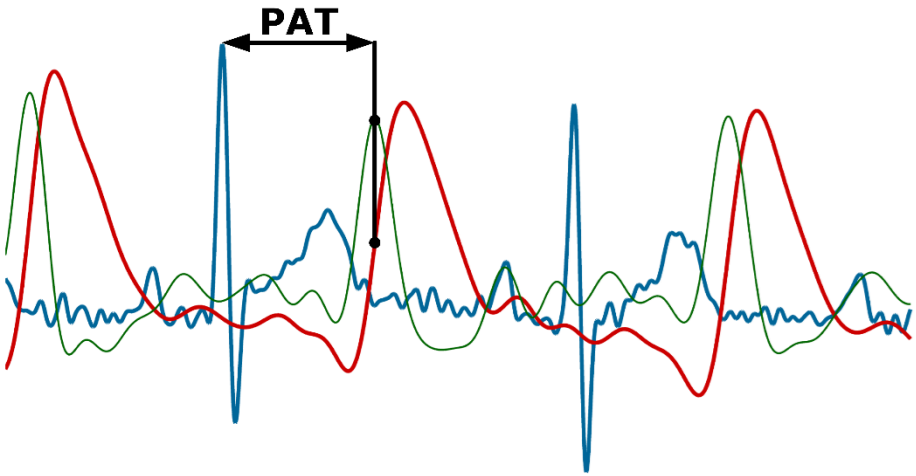
Can arterial stiffness be monitored in unobtrusive way, i.e. operatorless?

Arterial stiffness assesment

- Arterial stiffness can be characterized by the propagation of the pulse pressure wave (PPW) along the arterial tree.
- Pulse arrival time (PAT) – the time interval between the R-wave of the QRS complex and the particular point in the PPW.

PAT ↓

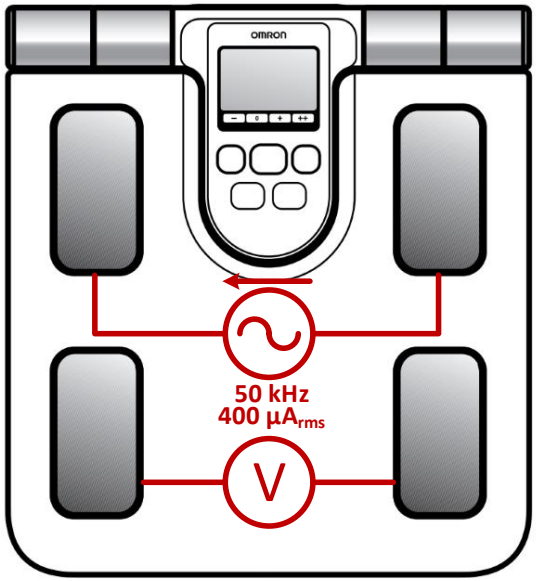
Arterial stiffness ↑



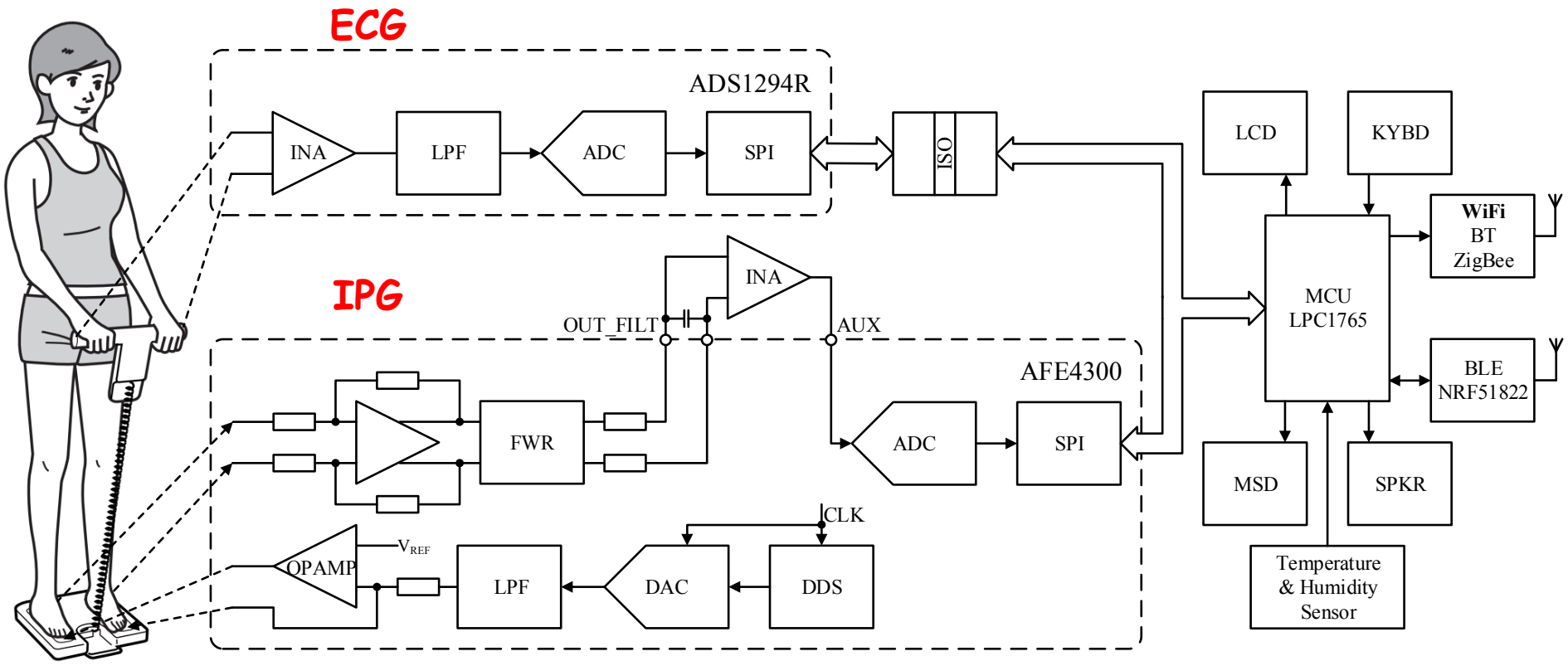
Solution (1)

- Impedance plethysmography (IPG) to determine changing tissue volumes (e.g. blood)
- ECG and IPG electrodes integrated into unobtrusive devices (e.g. bathroom scales)

IPG



Solution (2)


ECG
ADS1294R
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V_{REF}
LPF
DAC
DDS
LCD
KYBD
MCU
LPC1765
WiFi
BT
ZigBee
BLE
NRF51822
MSD
SPKR
Temperature
& Humidity
Sensor

Multiparametric Weight Scale: functionality

- Functionality:
  - body weight
  - biosignals: I,II,III ECG leads, 2 IPG ch., balistocardiogram, temp & humidity
  - WiFi: automatic sending of datafile to a remote server & receiving feedback
  - Matlab GUI / server algorithms for:
    - body fluids - bioimpedance parameters measurement
    - atrial fibrillation arrhythmia detection
    - **arterial stiffness – pulse arrival time estimation**
    - **ultrashort heart rate variability paameters**
    - slow (guided) breathing test

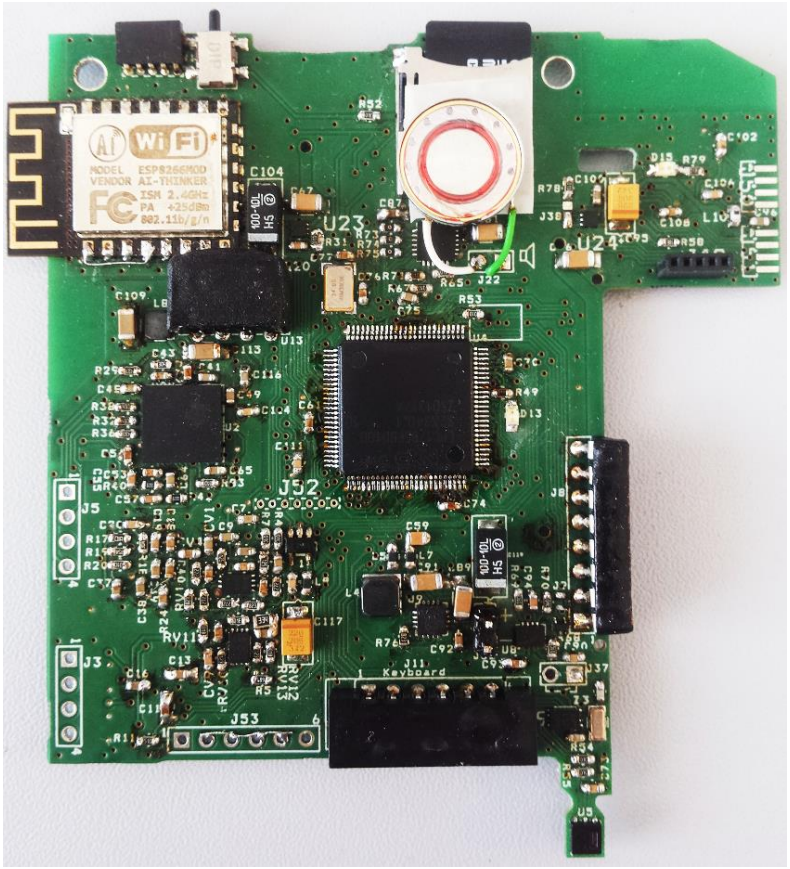
Multiparametric weight scale: hardware

- 3 microcontrollers
  - LPC1765, nRF52832, ESP8266
- Biosignals front-ends
  - ADS1294R, AFE4300 ADS1247
- Micro SD card
- WiFi & Low energy BlueTooth

1st prototype

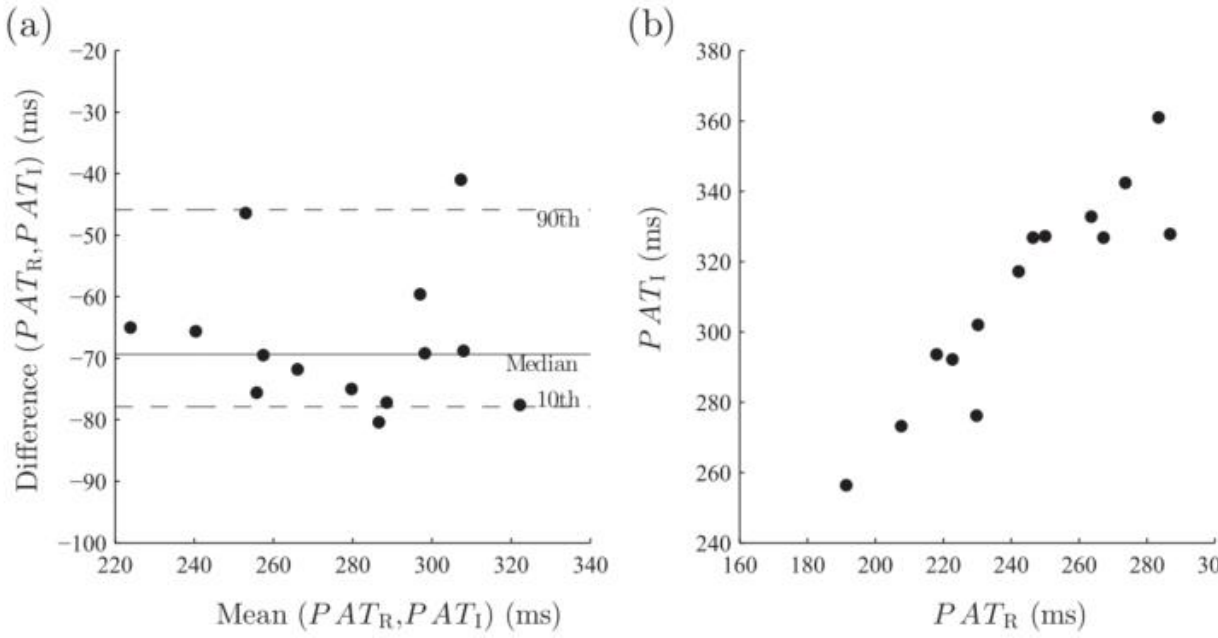
2nd prototype

Multiparametric weight scale : prototype v2



Pulse arrival time: validation

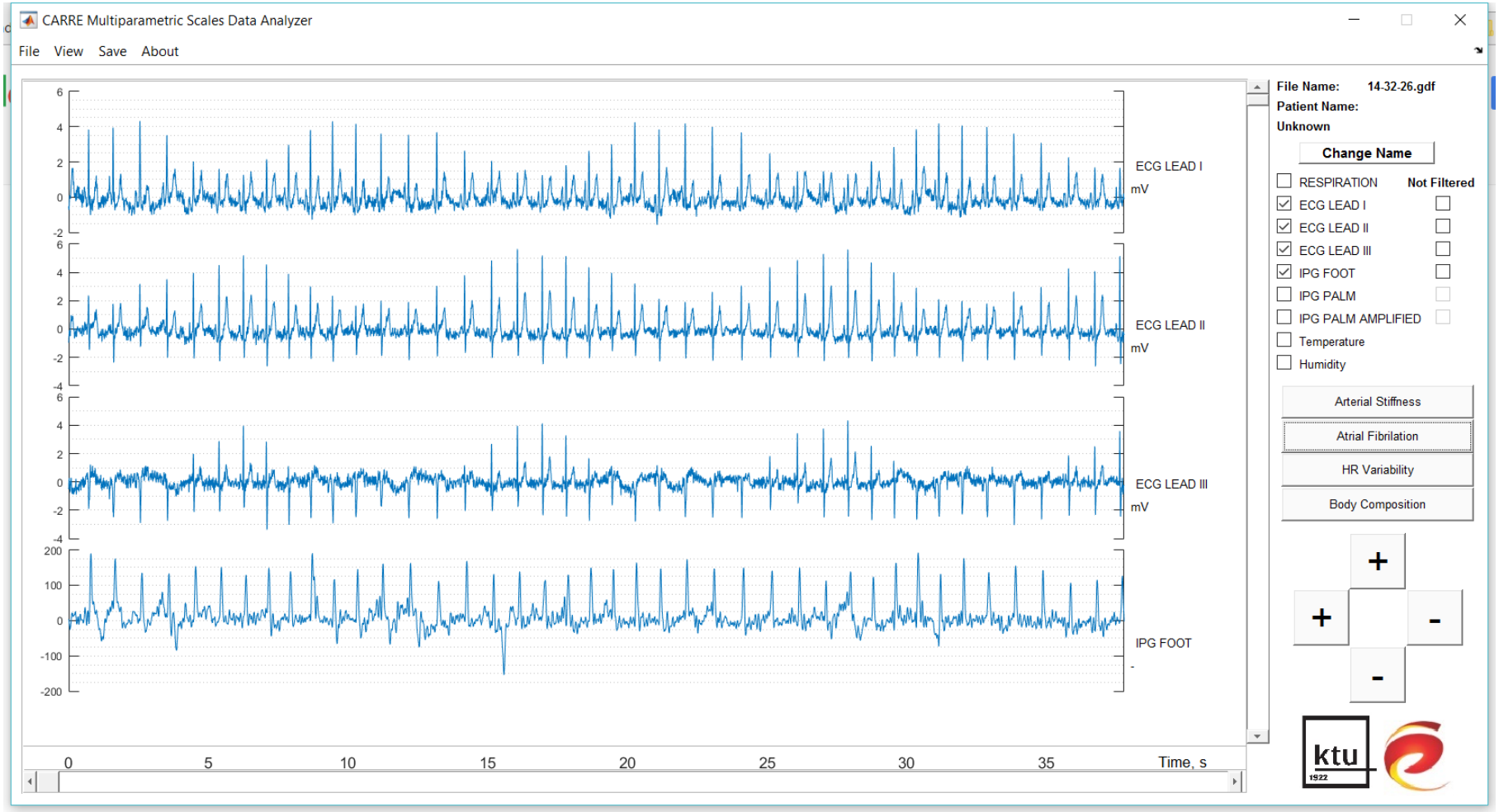
- 14 subjects
- Reference – tonometer (PulsePen, Italy)
- Results were published in:



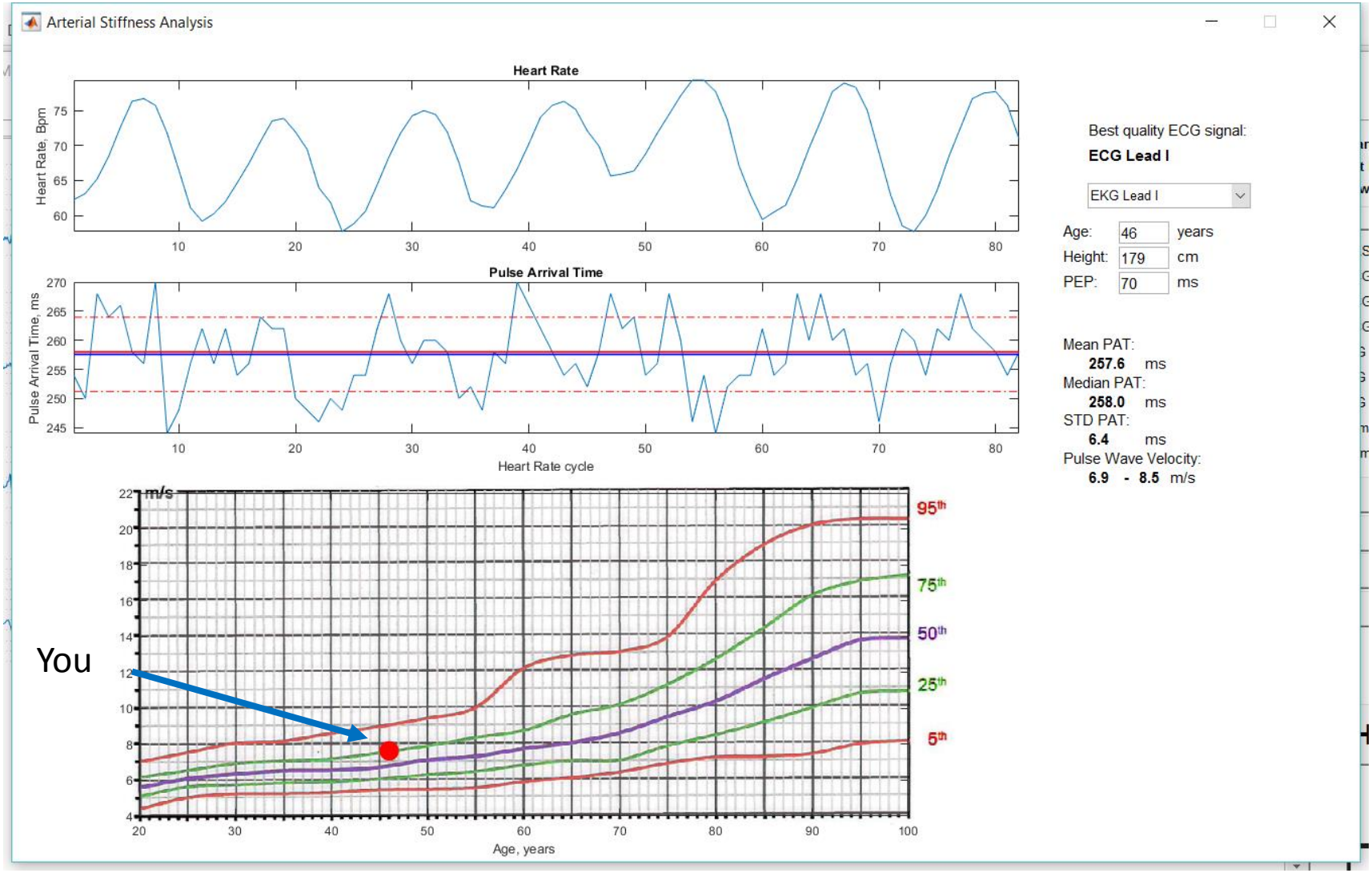
*Paliakaite B. et al. Estimation of pulse arrival time using impedance plethysmogram from body composition scales // *Sensors Applications Symposium* (SAS), 2015 IEEE , vol., no., pp.1-4, 13-15 April 2015 doi: 10.1109/SAS.2015.7133577

**Paliakaitė B. et al. Assessment of Pulse Arrival Time for Arterial Stiffness Monitoring on Body Composition Scales // Computers in Biology and Medicine, special issue: Self-monitoring systems for personalized health-care and lifestyle surveillance, available online April 22, 2016.

GUI: main window



Arterial stiffness analysis window



Summary

Two devices were developed that potentially could be applied for monitoring in unobtrusive way the effectiveness of electrical VNS-based treatment:

- Wrist-worn device - for long-term monitoring and closed loop treatment of paroxysmal atrial fibrillation
- Multiparametric scales – for home based monitoring of efficacy of VNS based treatment in peripheral artery disease patients.

Acknowledgement

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Thank you

Ready to collaborate experts in signal processing, sensors, embedded systems
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