Multimodal Unobtrusive Devices for Chronic Disease Monitoring

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Plan

- Motivation – chronic diseases

- Promises of vagus nerve stimulation 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

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”


Solution to prevent AF?

How to continuously monitor AF in unobtrusive way?
Medical background – AF heart arrhythmia

**Normal rhythm**

- Regular atrial contractions (P waves)
- Continuous atrial activity (f waves)
- Regular ventricular contractions

**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.

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
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

- **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.

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
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

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<th>Photoplethysmogram</th>
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<td>Sensitivity, %</td>
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<td>Sarkar et al.</td>
<td>99.9</td>
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<td>Petrènas et al.</td>
<td>99.4</td>
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Detection of self-terminating AF

Electrocardiogram

Photoplethysmogram

Amplitude-integrated motion
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:

AF? \rightarrow VNS stimulator \rightarrow Vagus- afferent \rightarrow Vagus- efferent \\
\rightarrow Pulse
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 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.
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)
Solution (2)
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 parameters
    - 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:


GUI: main window
Arterial stiffness analysis window
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.
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Thank you

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