nano-tera.ch
swiss scientific initiative in health / security / environment systems

ObeSense RTD 2013

Estimating the Real-Time Respiratory Rate from the ECG with a Bank of Notch Filters

Leila Mirmohamadsadeghi, Jean-Marc Vesin

Applied Signal Processing Group, Swiss Federal Institute of Technology EPFL, Lausanne, Switzerland

Introduction

- **Goal:** Estimate the respiratory rate from the heart beat (ECG) with low delay
- **Waveforms:**
  - Respiratory sinus arrhythmia (RSA)
  - Respiratory modulation of R-peak amplitudes (RPA)
- **State-of-the-art:** Fast Fourier transform or adaptive filters
- **Shortcomings:** Large delays
- **Proposed algorithm:** based on the outputs of a bank of notch filters

Conclusions

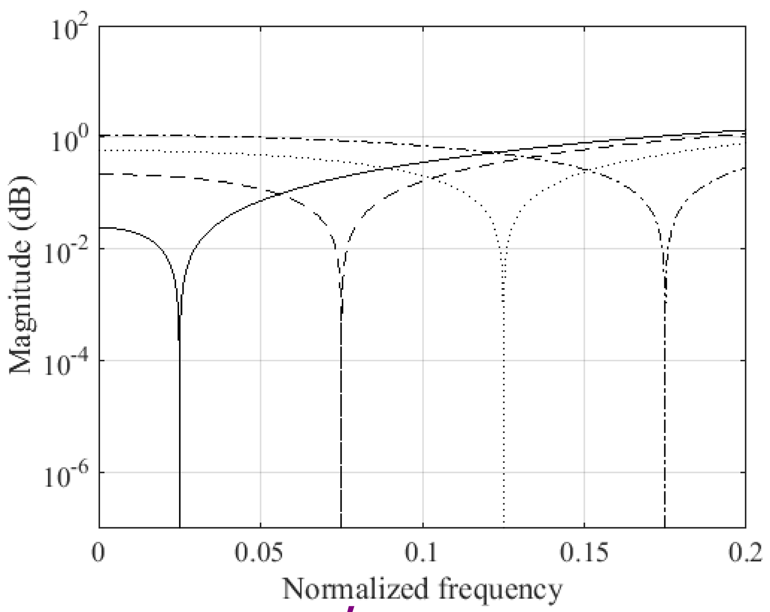
- Respiratory rate estimates are **accurate** (lower error than the state-of-the-art)
- The estimates have **low delays**
- Algorithm is **moderately sensitive** to its parameters

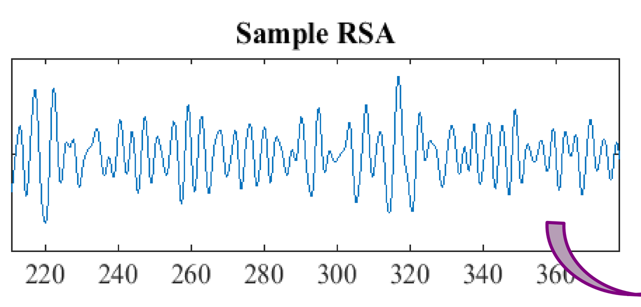
✓ **Good candidate for mobile health monitoring, e.g., with a smart-shirt as in ObeSense**

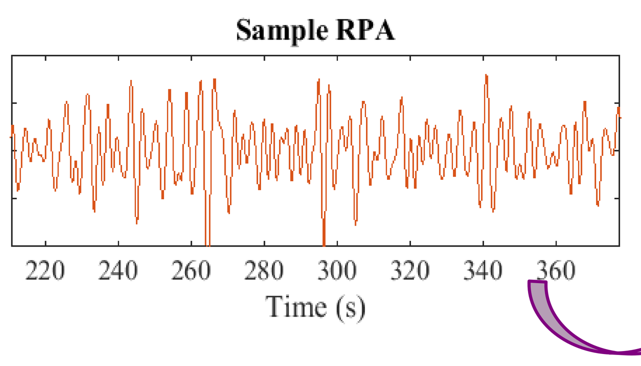
Methods

Algorithm input

- RSA: heart beat-to-beat distances
- RPA: heart beat amplitudes
  - re-sampled @ 4 Hz
  - filtered 0.1-0.5 Hz







Algorithm flow

Order-3 FIR filters

$Eq. 1$: $H(z) = 1 - 2z^{-1}\cos(2\pi f_i) + z^{-2}$

$Eq. 2$: $y_i[n] = u[n] - 2u[n-1]\cos(2\pi f_i) + u[n-2]$

$Eq. 6$: $w_i[n] = \frac{1}{Nsig}\sum_{j=1}^{Nsig} P_{i,j}[n]$

$Eq. 7$: $W_i[n] = \exp\left(-\min_i P_{i,j}[n]\, w_i[n]\right)$

Averaging: single weight over all inputs
Exp: large weights for small powers

$u_1[n]$ → norm Eq. 5 → $U_1[n]$; $u_1[n]$ → filtering Eq. 1,2 → $y_{1,1}[n],\dots,y_{1,N}[n]$ → power computation Eq. 3,4 → $P_{1,1}[n],\dots,P_{1,N}[n]$

$u_2[n]$ → norm Eq. 5 → $U_2[n]$; $u_2[n]$ → filtering Eq. 1,2 → $y_{2,1}[n],\dots,y_{2,N}[n]$ → power computation Eq. 3,4 → $P_{2,1}[n],\dots,P_{2,N}[n]$

→ weight computation Eq. 6,7 → $W_1[n],\dots,W_N[n]$ → summation Eq. 8 → $f[n]$

$Eq. 8$: $f[n] = \frac{\sum_{i=1}^{N} W_i[n] f_i}{\sum_{i=1}^{N} W_i[n]}$

$Eq. 5$: $U[n] = \delta U[n-1] + (1-\delta)u^2[n]$

Recursive mean square value

$Eq. 3$: $P_i[n] = \delta P_i[n-1] + (1-\delta)c_i^2[n]$

$Eq. 4$: $c_i[n] = y_i[n]/\sqrt{U[n]}$

Recursive output normalized with respect to input

Algorithm output: f: frequency estimate. Weighted sum of notch frequencies

Test data

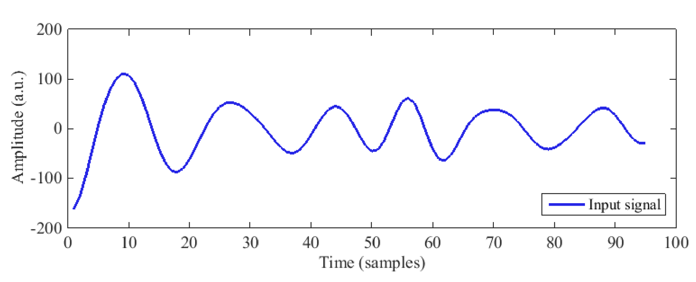
- PhysioNet Fantasia data set
- Single-lead ECG and respiration
- 40 subjects: young and elderly
- 2 hour recordings/subject

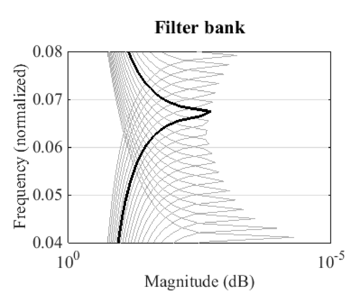
Results

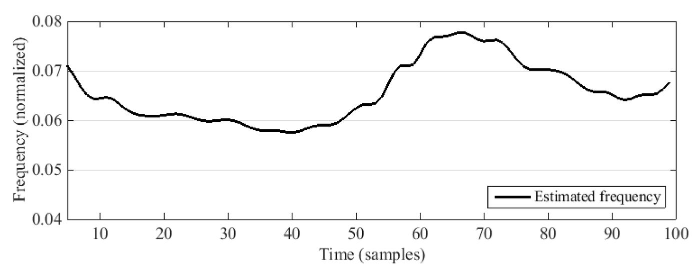
Illustration of the algorithm

- With a single input:

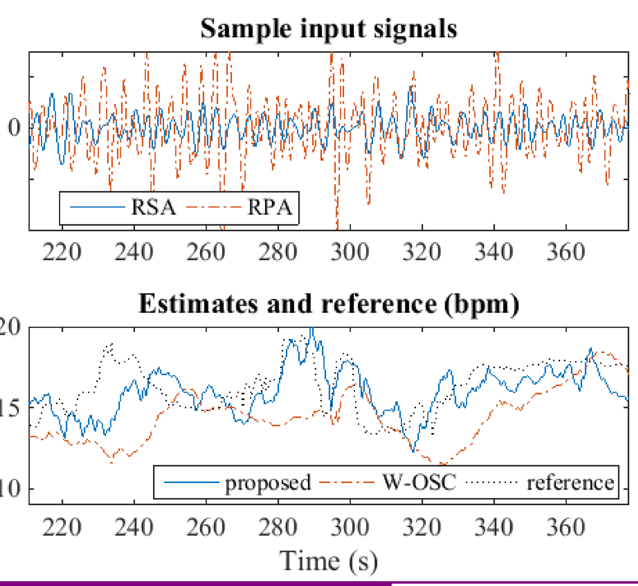
Link to video:



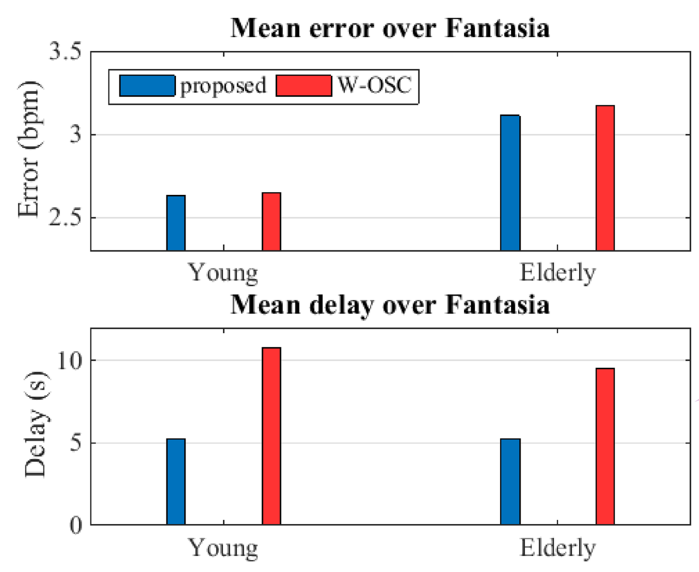




- With two inputs:



Performance



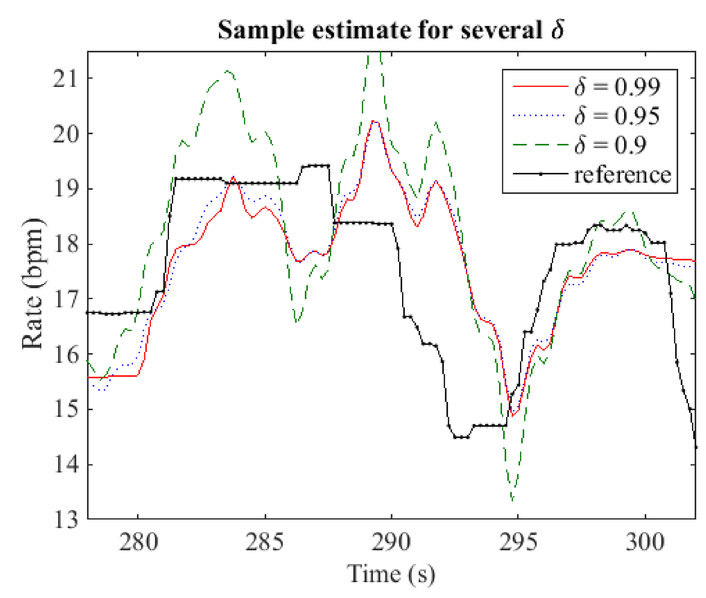
✓ **Lower error than the W-OSC**

✓ **Half the delay of the W-OSC**

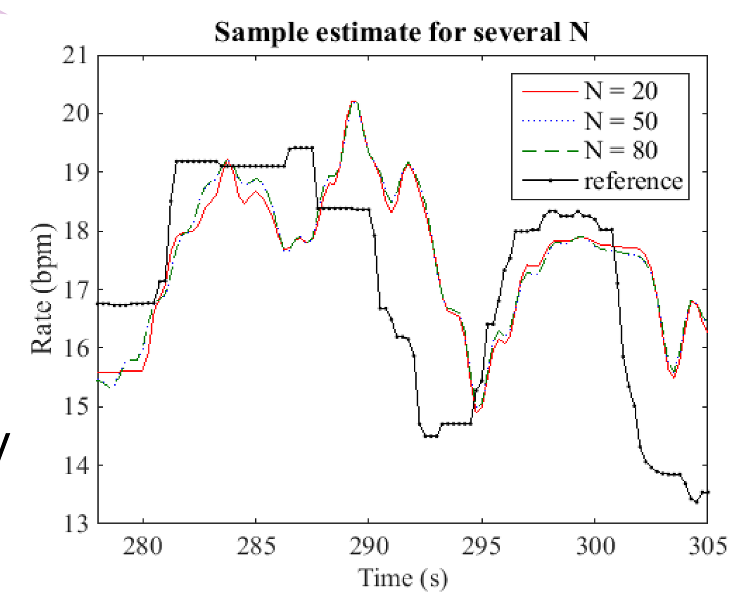
- Mean absolute error (bpm)
- Delay (seconds, measured by correlation analysis)
- Comparison to the state-of-the-art adaptive filter (W_OSC method [1])

[1] Mirmohamadsadeghi and Vesin, Biomed Signal Process Control, 2014

Sensitivity analysis



✓ **Moderate (low) sensitivity**



- High N: less quantization ↔ more computations
- High δ: less variability ↔ slower adaptation

Contact: asp.epfl.ch
leila.mirmohamadsadeghi@epfl.ch