Respiratory Rate Estimation from Multi-Lead ECGs using an Adaptive Frequency Tracking Algorithm

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Introduction

- **Goal:** Estimate the respiratory rate (RR) from multi-lead ECGs
- **Waveform:** Respiratory modulation of R-peak amplitudes (RPA)
- **State-of-the-art:** Temporal or Fourier-based RR estimation using single-lead RPA
- **Shortcomings:** low accuracy and weak generalization
- **Proposed algorithm:** weighted adaptive oscillator-based (W-OSC) frequency tracking[1] to use multiple ECG leads
- **Dataset:** PhysioNet MGH/MF (Fig. 1)

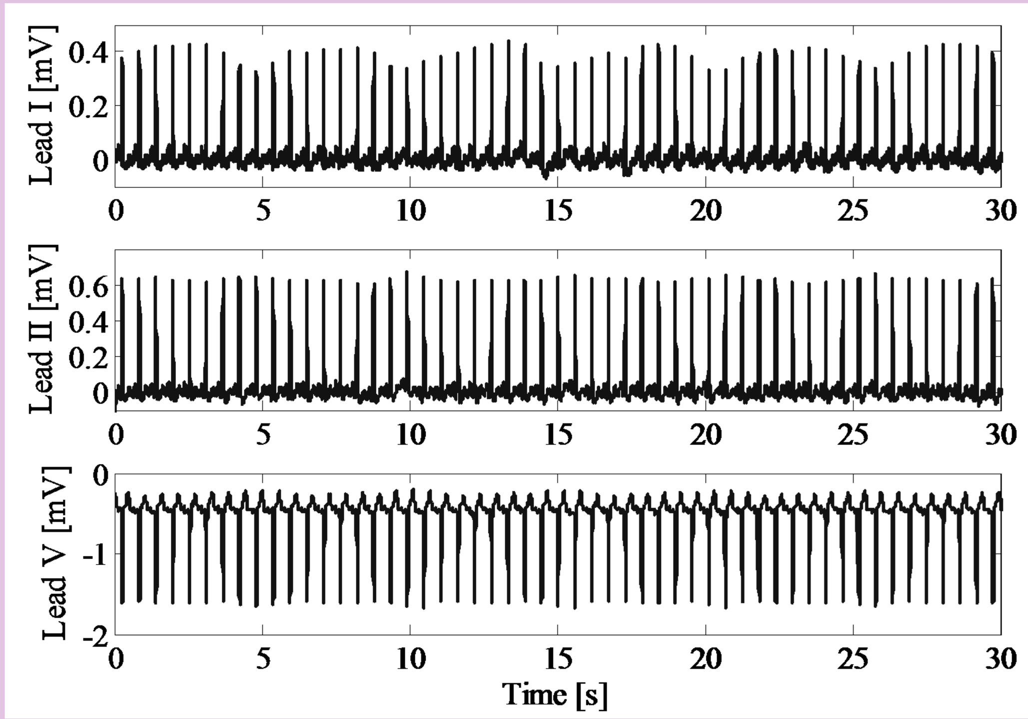

Fig. 1: A sample multi-lead ECG.

Methods

Dataset

- 20 records from the PhysioNet MGH/MF dataset, 7 females, 13 males, aged 49-84, total of 41.7 hours
- 17 had cardiac surgery; 17 had an arrhythmia; 8 were under controlled respiration
- ECG leads I, II, an un-identified V lead (Fig. 1) and the respiratory impedance

Signal processing

A) RPA extraction

- R-peak amplitude extraction
- Re-sampling at 4 Hz
- Band pass filtering 0.1-0.5 Hz

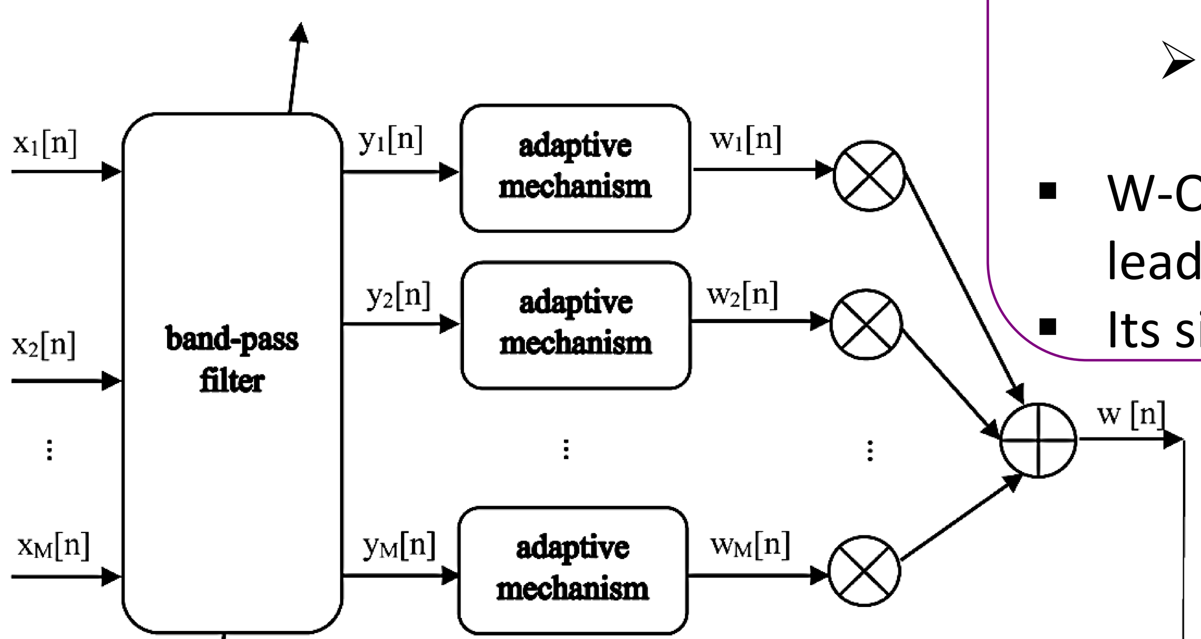

Fig. 2: The W-OSC algorithm. $x_i[n]$: inputs; $y_i[n]$: output of filter; $w_i[n]$: estimate of each input; w[n]: final estimate.

B) W-OSC Frequency tracking

- All inputs $x_M[n]$ were filtered with band-pass filter (Fig. 2)
- Central frequency of filter was updated
  - The error between the output and a perfect oscillation was minimized
  - Each input was weighted based on the signal-to-noise ratio of its filtered output
- W-OSC was Applied to RPAs from pairs of leads and all three leads
- Its single-input version (OSC) was applied to each lead

C) State-of-the-art

- Maximum frequency was estimated from Short-time Fourier transform

D) Reference RR

- Respiratory impedance was filtered
- Five classic estimates were combined: Fourier, number of peaks, time-lapse between peaks, Teager-Kaiser operator, autoregressive modelling

Illustrative video:

E) Evaluation

- Mean absolute error computed in breaths-per-minute (bpm)

1 Prudat Y, Vesin JM. Multi-signal extension of adaptive frequency tracking algorithms. Signal Process. 2009;89(6):963–973.

Results

Illustrative examples

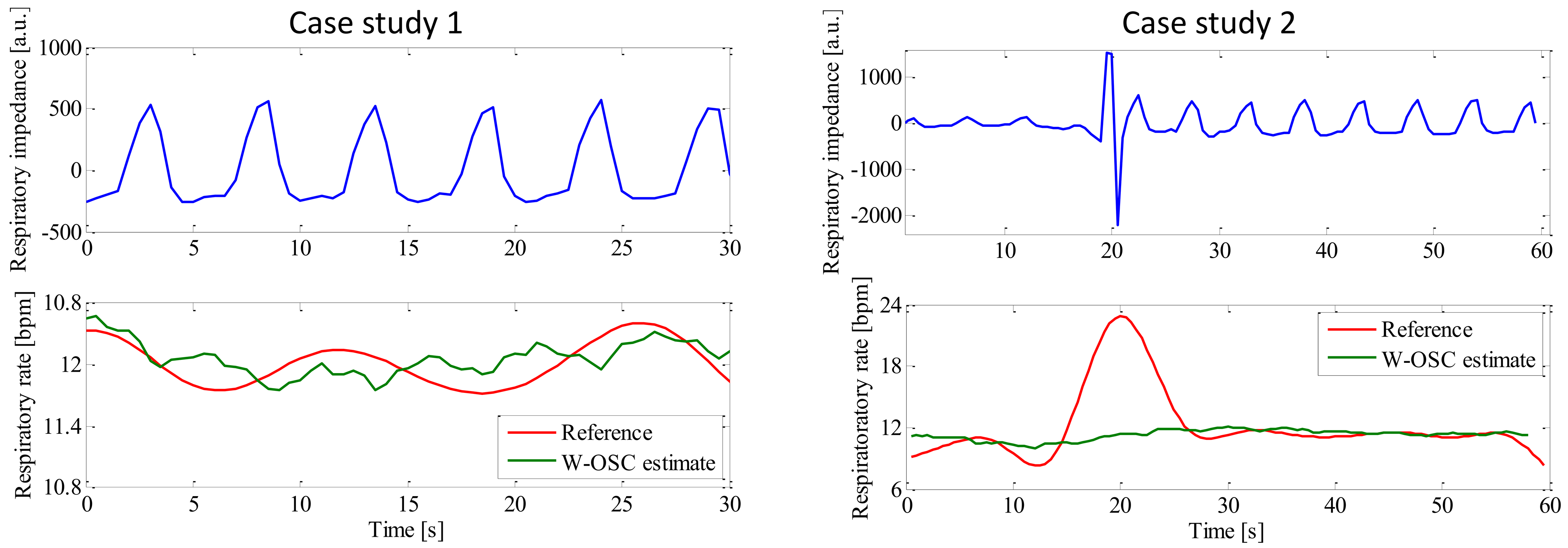

Fig. 3: Sample respiration (top plots) and estimated RRs (bottom plots). Case study 1 shows a successful RR estimation. Case study 2 shows that the classic methods capture an artifact contrary to W-OSC.

Accuracy

- Lowest error -> W-OSC
- Highest error -> Fourier (Fig. 4)

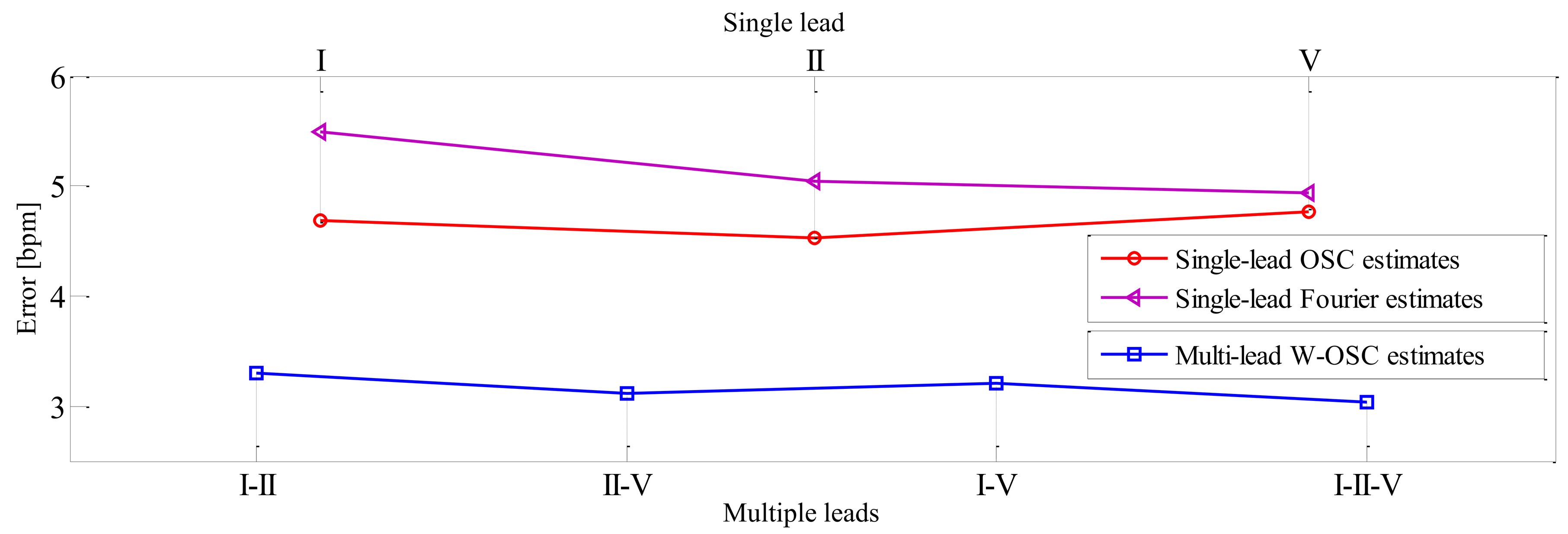

Fig. 4: Average errors over all records of the W-OSC compared to those of the OSC and Fourier estimates.

Universality

- Algorithms apply to cardiac patients
- Algorithms apply for spontaneous or controlled respiration

Convenience

- Algorithms are automatic
- Estimates are real-time and robust

Conclusions

- The RR can be estimated in clinical situation from a multi-lead ECG acquisition.
- Using respiration modulation from **several leads is better than** using one lead.
- The OSC and W-OSC outperform Fourier-based estimation.
- The W-OSC is **instantaneous** and **automatic.**
- The W-OSC is largely effective in cases of **cardiac conditions** and **arrhythmias.**

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