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Wavelet Based Denoising for Suppression of Respiratory and Motion Artifacts in Impedance Cardiography

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Abstract: **Impedance cardiography senses the variation in the thoracic impedance caused by variation in the blood volume and it is used for estimating the stroke volume and other cardiovascular indices. Respiratory and motion artifacts in the sensed signal introduce errors in these estimations. A denoising technique, using discrete Meyer and symlet-26 wavelets, with scale-dependent thresholding for suppressing the respiratory artifact and limiting of the wavelet coefficients for suppressing the motion artifact is investigated. Denoising of signals with simulated respiratory artifacts improved the signal-to-artifact ratio by 23.5 dB. Denoising of signals with real respiratory and motion artifacts resulted in the values of L2 norm and max-min based improvement indices being close to one, indicating effective suppression of artifacts without any significant signal distortion.**

1. Introduction

Impedance cardiography

A noninvasive technique based on sensing the variation in the thoracic impedance $Z(t)$ caused by variation in the blood volume in the thorax.

ICG = $-\,dZ/dt$

Applications: **Estimation of stroke volume and other indices for cardiovascular diagnosis**

Main artifacts leading to errors in identification of characteristic points: **respiratory, motion**

ICG bandwidth: 0.8 – 20 Hz,
Respiratory artifact: dc – 2 Hz,
Motion artifact: 0.1 – 10 Hz

Limitations of artifact suppression techniques

- ***Patient lying in supine position holding the breath:*** **limited duration recording.**
- ***Ensemble averaging:*** **smearing of characteristic points.**
- ***LMS-based adaptive filtering:*** **need of a reference related to the artifact.**
- ***Wavelet based scale-dependant thresholding:*** **effective against only the respiratory artifact.**

2. Signal Processing

Observations from wavelet analysis of ICG

Dmey & Symlet-26 based 10-level decomposition of ICG sampled at 500 Hz

- **Signal components up to D8.**
- **Insignificant contribution from respiratory artifact up to D8.**
- **Noise-free ICG: all the coeff. mag. below a certain value & nearly uniformly distributed.**
- **ICG with motion artifact: large variations in some of the coeff. mag.**

Proposed wavelet based denoising

- **Suppression of respiratory artifact: Scale-dependent thresholding by resynthesis using D1-D8**
- **Suppression of motion artifact: Resynthesis after limiting of wavelet coefficients**

Thresholds for coeff. limiting

- **Minimax threshold for D5–D8.**
- **Level-dependent thresholds for D1–D5**
  Signal divided in frames of twice the average R-R interval (with at least one cardiac cycle per frame).
  Threshold for each scale = mean of the maximum of the coeff. mag. in each frame

3. Evaluation

Material

ICG recordings, using (i) ICG instrument developed in our lab, (ii) HIC2000, at S.R. = 500 Hz.

- **Set A (2 healthy S's)**
  - **Artifact-free recording in supine position with breath hold.**
  - **Recording with respiratory artifact but no motion artifact.**
  - **Recording with both types of artifacts.**
- **Set B (20 healthy S's): Signals with simulated respiratory artifacts, generated using**
  - **artifact-free ICG**
  - **ICG-free artifact obtained by ensemble averaging of ICG with periodic breathing**

Method

Qualitative

Observation of the waveforms for artifact suppression and signal distortion

Quantitative

Improvement in signal-to-artifact ratio of signals with simulated respiratory artifact

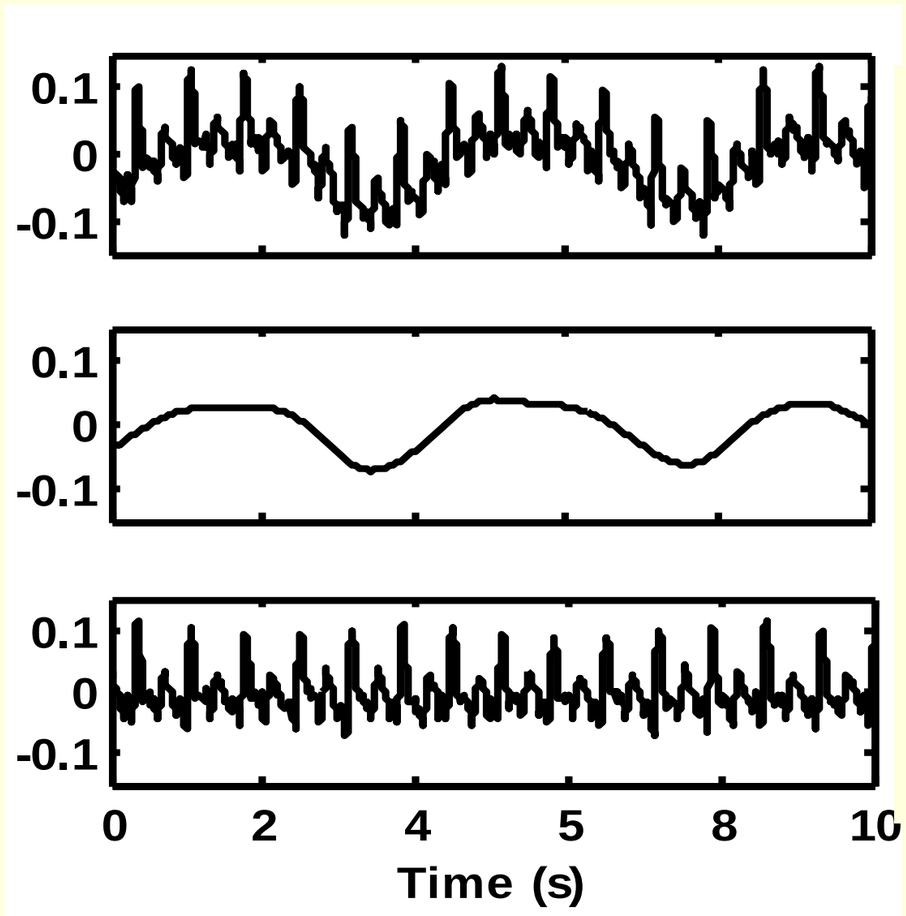
Signal L2-norm & excursion (max-min) based improvement indices, with reference to artifact-free segments

$$\text{I.I.} = \left|(\text{Pre-denoising value} - \text{Post-denoising value})\right| \;/\; \left|\text{Pre-denoising value} - \text{Artifact free value}\right|$$

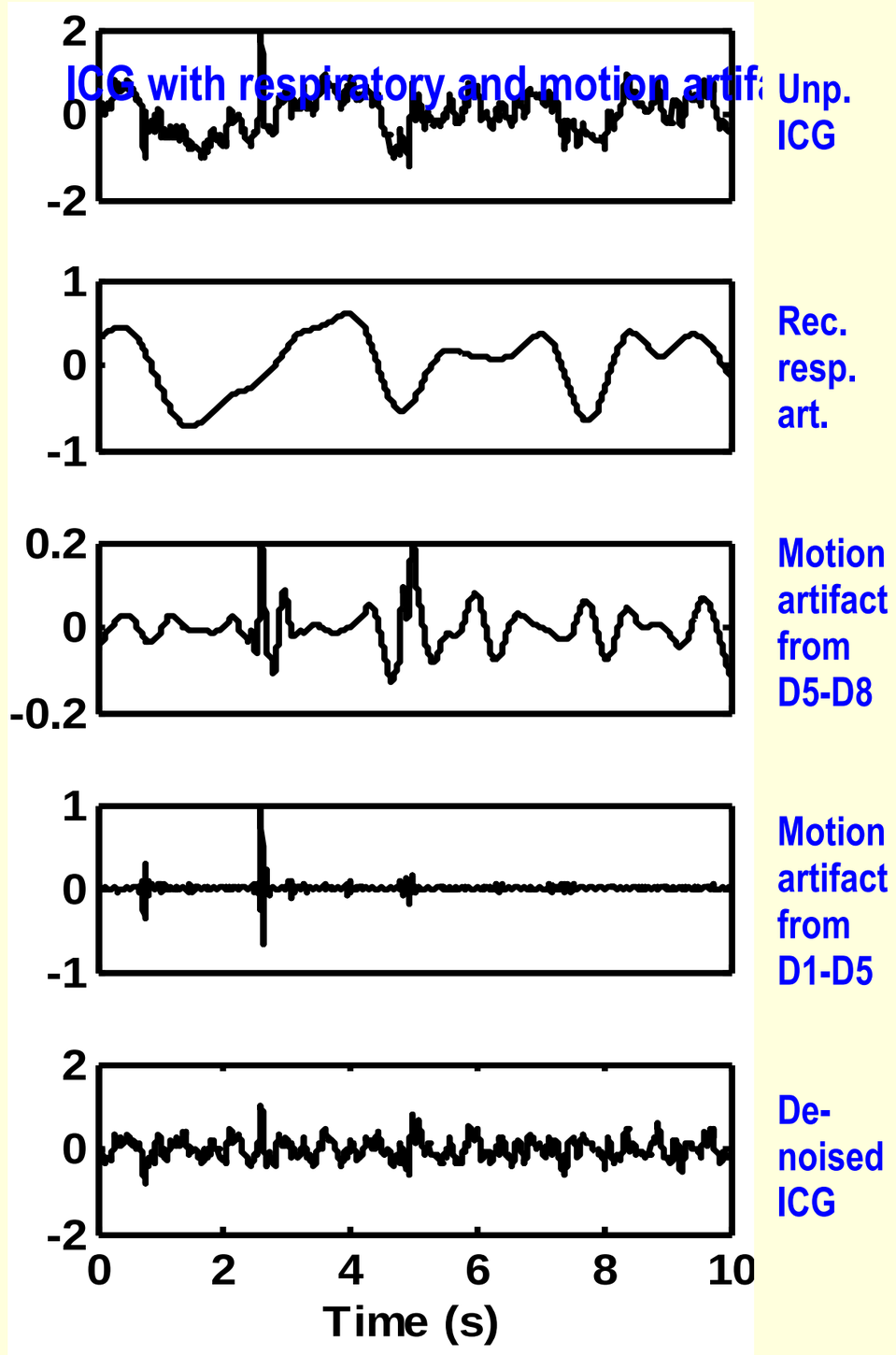
4. Results

Examples of artifact suppression (waveforms in Ω/s).

ICG with respiratory artifact (S: C6)



ICG with respiratory and motion artifa 4)



Application on signals with simulated respiratory artifacts for input SAR of -9, -3, 3, and 9 dB

SAR improvements: 23.5, 19.6, 15.0, and 9.9 dB.

L2-norm I.I.: 1.01, 1.25, 1.06, and 1.4

Suppression of actual respiratory and motion artifacts

Average indices for 33 segments (each of 10 s) from two subjects: 1.02

5. Conclusion

Result summary

Effective suppression of respiratory & motion artifacts, without introducing signal distortion.

Further work

Evaluation by validating the values of SV & other indices w.r.t. reference techniques.

Application of impedance cardiography for ambulatory and stress test recordings.