# Wavelet Based Denoising for Suppression of Motion Artifacts in Impedance Cardiography

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## Introduction

Impedance cardiography is a noninvasive technique for monitoring the changes in the electrical impedance of the thorax $z(t)$, caused by variation in the blood volume during the cardiac cycle [1]. Time derivative of the thoracic impedance is known as the impedance cardiogram (ICG) and it is used for estimating the ventricular ejection time ($T_{lvet}$), the negative peak of ICG ($(-dz/dt)_{max}$), the stroke volume, and some other cardiovascular indices. Respiratory and motion artifacts cause baseline drift in the sensed impedance waveform, particularly during or after exercise, and this drift results in errors in the estimation of the parameters [1], [2]. Ensemble averaging [2], generally employed for suppressing the artifacts, suppresses the beat-to-beat variations and tends to smear the peak in the ICG. It may blur or suppress the less distinctive characteristic points in the waveform and hence may result in error in their detection. Due to a partial overlap between the spectra of ICG and the artifacts, non-adaptive digital filters are not effective in removing the artifacts. Adaptive filtering may be used for canceling the respiratory artifacts [3], but it is generally difficult to sense the references related to the sources of various motion artifacts and to combine them.

Earlier we have investigated a wavelet based denoising technique for suppression of the respiratory artifact from ICG signal [4], in order to facilitate estimation of stroke volume on beat-to-beat basis. In present study, we examine the applicability of the denoising technique for cancellation of the motion artifact from the ICG signals, without smearing the beat-to-beat variations.

## Materials and Methods

Our technique uses discrete wavelet transform (DWT) based linear denoising, or scale-dependent thresholding. Using dyadic multiresolution analysis, the signal is decomposed to a number of scales, and each scale is reconstructed into the details and the approximation, to visualize the signal and artifact component at each scale [5]. For decomposition, we studied several types of wavelets: Daubechies, coiflets, symlets, FIR Meyer, and biorthogonal for the signal acquired at sampling frequency of 500 Hz. The FIR based Meyer wavelet captured the ICG in its first few scales and the artifacts in the other scales for a wide variation in the heart rate, respiration, and the motion artifacts. It was found that decomposing the signal up to 10 scales gave sufficient resolution to separate the signal and the artifact.

The effectiveness of the technique in removing the motion artifact was investigated by processing the signals corrupted by motion artifacts but free from respiratory artifacts. The signals were recorded with the subject holding the breath (to avoid respiratory artifact) and causing hand or other motions, from seven professional swimmers who could comfortably hold the breath for a relatively long period. Impedance cardiograph

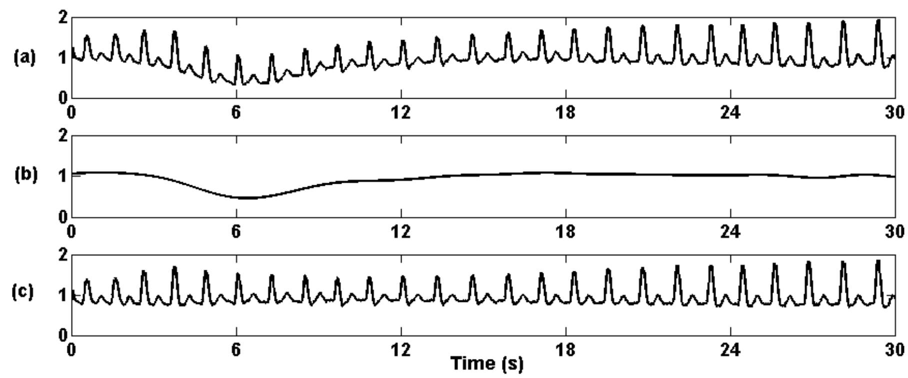


**Fig. 1** Processing of ICG by WBD with motion artifact: **(a)** recorded ICG (in Ω/s), **(b)** estimated artifact (in arbitrary units), and **(c)** processed ICG (in Ω/s), from subject 'JJ'.

instrument was used for recording of ICG waveforms, by injecting a high frequency (100 kHz), low intensity (<5 mA) current into the thorax. Four-electrode configuration with disposable ECG spot electrodes was used. In the outer pair, one electrode was placed around abdomen at the lateral side of the lower ribs and the other around upper part of the neck. For the inner electrode pair, one electrode is placed around the thorax at the level of joint between xiphoid and sternum and the other around the lower part of the neck.

## Results and Conclusion

Figure 1 shows a signal from a volunteer 'JJ'. Recordings were taken with the breath held for 30 s and left hand movement. In the waveform shown in Fig. 1(a), the ICG is contaminated by only the motion artifact. After applying the wavelet based denoising, the motion artifact is suppressed and a stable baseline is achieved improving the estimation of various cardiovascular parameters from the waveform, as seen in Fig. 1(c). Applying the technique on artifact-free signals (acquired during breath hold and without any motion) did not introduce any significant distortion in the signal.

A visual examination of the waveforms obtained after application of the technique, on recordings from the seven volunteers with hand motion and with as well as without breathing, showed that the technique was effective in suppressing the motion and respiratory artifacts without any degradation in the ICG signal, thus facilitating beat-by-beat estimation of stroke volume and other cardiovascular indices from the waveform, particularly during or after exercise.

## References

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