Comparison of Fetal Phonocardiogram Wavelet Denoising Methods

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Fetal heart sounds have always been one of the main parameters to focus on in terms of monitoring the well-being of a fetus. In the past, intermittent auscultation was the main technique in midwifery and obstetrics, and Pinard Horn the main equipment of the clinicians. The accuracy of the method was highly dependent on the skills and experiences of the examiner [1]. This method was later replaced by the continuous Electronic Fetal Monitoring (EFM), also known as Cardiotocography (CTG), using Doppler Effect for monitoring of the fetal heart rate (fHR). By using the computer technology, the performance of the method should be higher than intermittent auscultation. However, many studies claim that this presumption is questionable [2, 3]. Moreover, the drawback of Doppler-based EFM is that it does not allow to monitor fetal heart rate variability. Therefore, some short time changes may occur unnoticed [4].

In the last few years, the fetal heart sounds monitoring has been reborn in the fetal phonocardiogram (fPCG). In comparison with intermittent auscultation, this method allows digitalization of the heart sounds and thus more objective computer based evaluation and analysis [5]. Moreover, in contrast to the CTG, it allows to assess heart rate variability and detection of some additional features obtained in the fPCG signal (such as subaudible sounds, murmurs, etc. [6]). Thus, this method has great potential to improve the quality of fetal monitoring. However, it suffers from the noise that is being sensed with the desired signal. Traditional denoising methods using linear filters for the fPCG noise removal face certain limitations due to the non-stationarity of the fPCG signals. Therefore, to improve the diagnostic capabilities of this method, a lot of recent studies focus on fPCG signal denoising using advanced signal processing methods [7 – 10].

In this presentation, we introduce the discrete wavelet transform for denoising the abdominal fPCG recordings. Many authors have proposed different approaches and settings of the wavelet-based fPCG filtration system [10 – 14]. There are three main parameters that need to be selected carefully, namely wavelet base, thresholding method, and level of decomposition. Most of the published works [12 – 15] present heuristic approaches in selecting these parameters. Experimental part of this presentation introduces an objective optimization technique that can help in assessing the validity of the parameter for given purpose.

The experiments were carried out on both synthetic and real abdominal PCG data. The synthetic data were used to perform the optimization and evaluation of the denoising system. First phase consisted of optimization of the system parameters: wavelet family and the level of decomposition. We tested the members of orthogonal and biorthogonal wavelet families (sym3 – sym8, db1 – db10, coif1 – coif5, bior 1.1, bior 1.3) for 6 levels of decomposition. In the second phase, fixed threshold configuration (designed within this research) is compared with the conventionally used thresholding methods included in Matlab Wavelet Toolbox, namely Rigorous SURE, Heuristic SURE, and Minimax.

The results showed that our thresholding method, which minimizes the detail coefficients at level 1, 5, and 6, outperforms the rest of the tested thresholding techniques. Moreover, in contrast to Chourasia in [11], the best results were obtained for the decomposition on level 6 in case of the most of the tested wavelet families; the most suitable wavelet families are Daubechiens (Db10) and Biorthogonal (Bior2.8) wavelets. For the final verification of the results obtained using synthetic data, we used recordings from Fetal PCG

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Database (fpcgdb) consisting of recordings from 16 patients from different stages of pregnancy [16, 17]. The system successfully suppressed most of the noise and enabled the fetal heart rate detection.

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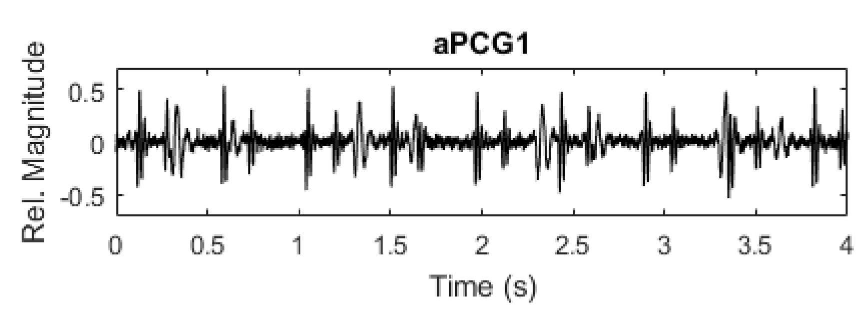
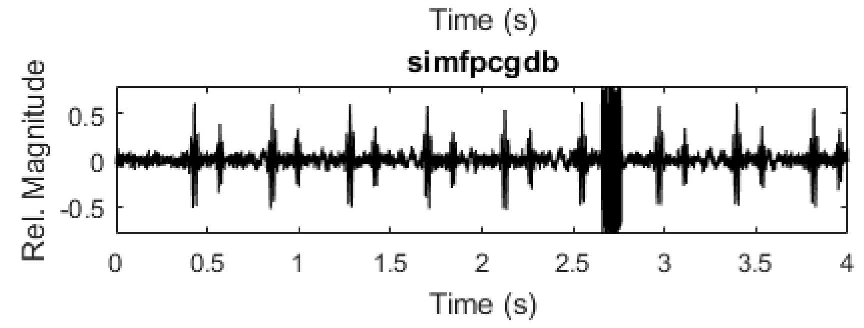
Abstract

- In the last few years, the fetal heart sounds monitoring has been reborn in the fetal phonocardiogram (fPCG).
- This method allows digitalization of the heart sounds and thus more objective computer based evaluation and analysis of fetal heart rate variability and detection of some additional features obtained in the fPCG signal (subaudible sounds, murmurs, etc.).
- However, it suffers from the noise that is being sensed with the desired signal. This presentation introduces the discrete wavelet transform for denoising the abdominal fPCG recordings to improve the diagnostic capabilities of this method.
- There are three main parameters that need to be selected carefully: the wavelet base, thresholding method, and level of decomposition. Most of the published presents heuristic approaches in selecting these parameters.
- Experimental part of this presentation introduces an objective optimization technique that can help in assessing the validity of the parameter for given purpose.

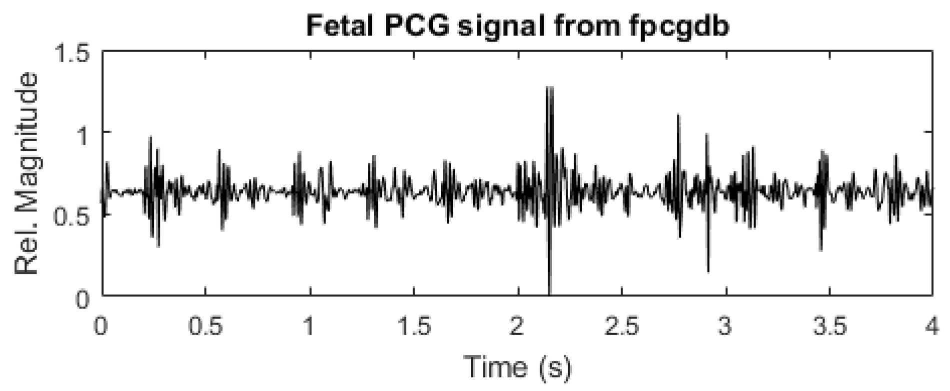
Dataset

- Simulated Fetal Phonocardiograms Database (simfpcgdb) is available online for researchers to test their algorithms. However, these data are very simple and the reference signals are not available.
- We used our own simulated PCG data, since mPCG, aPCGs, and ideal PCG signals are available for optimization purposes.
- Comparison of the data used for the experiments with fPCG signal from simfpcgdb:





- For the final verification of the results obtained using synthetic data, we used recordings from Fetal PCG Database (fpcgdb) which consists of records from 16 patients from different stages of pregnancy.



Experiments

- The experiments were carried out on both synthetic and real abdominal PCG data. The synthetic data were used to perform the optimization and evaluation of the denoising system.
- First phase consisted of optimization of the system parameters: wavelet family and the level of decomposition.
- We tested the members of orthogonal and biorthogonal wavelet families (sym3 – sym8, db1 – db10, coif1 – coif5, bior 1.1 – bior 1.8) for 6 levels of decomposition.
- Results for Coiflet family

Wavelet Family	Level	Wavelet family member				
		Coif1	*Coif2*	*Coif3*	*Coif4*	*Coif5*
Coiflet	lev1	0.0722	0.0724	0.0725	0.0725	0.0726
	lev2	0.0708	0.0710	0.0710	0.0711	0.0711
	lev3	0.0708	0.0710	0.0710	0.0711	0.0711
	lev4	0.0708	0.0710	0.0710	0.0711	0.0711
	lev5	0.0417	0.0395	0.0391	0.0391	0.0391
	lev6	0.0301	0.0285	0.0281	0.0280	0.0280

- Results for Symlet Family

Wavelet Family	Level	Wavelet family member					
		Sym3	*Sym4*	*Sym5*	*Sym6*	*Sym7*	*Sym8*
Sym	lev1	0.0723	0.0724	0.0725	0.0725	0.0725	0.0725
	lev2	0.0709	0.0710	0.0710	0.0710	0.0710	0.0710
	lev3	0.0709	0.0710	0.0710	0.0710	0.0710	0.0710
	lev4	0.0709	0.0710	0.0710	0.0710	0.0710	0.0710
	lev5	0.0403	0.0396	0.0392	0.0391	0.0390	0.0391
	lev6	0.0290	0.0285	0.0283	0.0281	0.0281	0.0280

- Results for Biorthogonal wavelets

WF	Level	Wavelet family member					
		Bior1.1	*Bior1.3*	*Bior2.2*	*Bior2.4*	*Bior2.6*	*Bior2.8*
Bior	lev1	0.0718	0.0722	0.0722	0.0723	0.0725	0.0725
	lev2	0.0701	0.0708	0.0708	0.0709	0.0710	0.0710
	lev3	0.0701	0.0708	0.0708	0.0709	0.0710	0.0710
	lev4	0.0701	0.0708	0.0708	0.0709	0.0710	0.0710
	lev5	0.0473	0.0419	0.0422	0.0406	0.0390	0.0391
	lev6	0.0364	0.0303	0.0312	0.0296	0.0281	0.0280

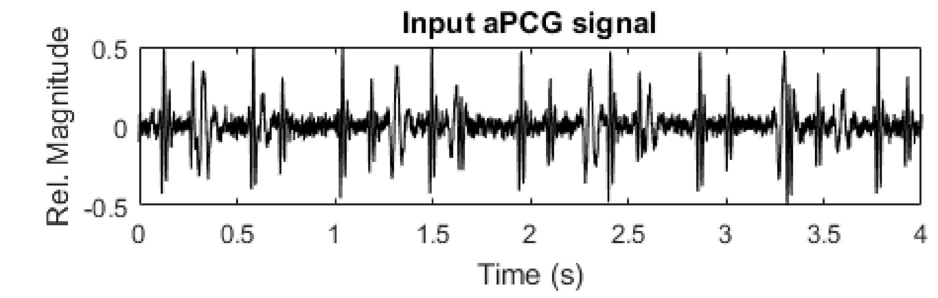
- Results for Daubechiens wavelet family:

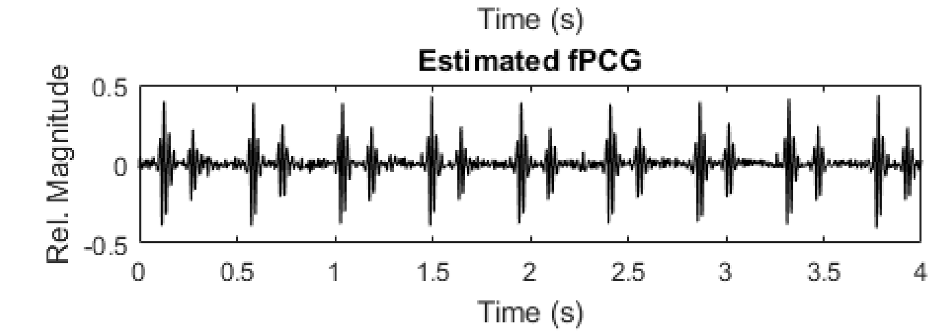
WF	Level	Wavelet family member					
		Db2	*Db4*	*Db6*	*Db8*	*Db9*	*Db10*
Db	lev1	0.0722	0.0724	0.0725	0.0725	0.0726	0.0726
	lev2	0.0708	0.0710	0.0710	0.0710	0.0711	0.0711
	lev3	0.0708	0.0710	0.0710	0.0710	0.0711	0.0711
	lev4	0.0708	0.0710	0.0710	0.0710	0.0711	0.0711
	lev5	0.0419	0.0395	0.0390	0.0390	0.0390	0.0390
	lev6	0.0303	0.0285	0.0281	0.0280	0.0279	0.0279

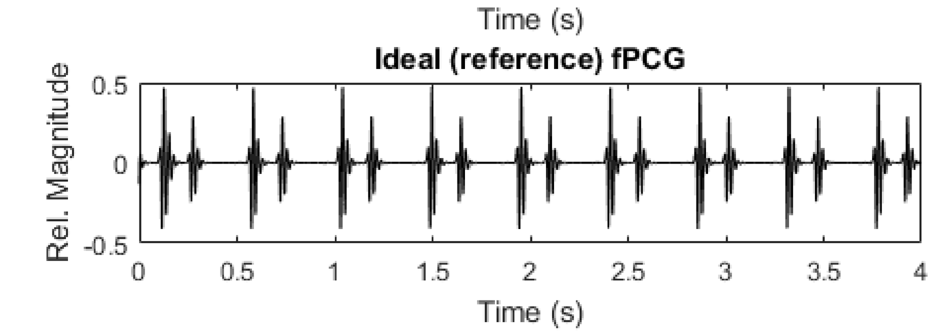
- In the second phase, fixed threshold configuration (designed within this research) is compared with the conventionally used thresholding methods included in Matlab Wavelet Toolbox, namely Rigorous SURE, Heuristic SURE, and Minimax.
- The estimated fPCG signals were assessed by three objective parameters: Signal to Noise ratio (SNR), Percentage Root-Mean-Square Difference (PRD), and Root Mean Square Error (RMSE). This way, we determined the best wavelet family configuration for the denoising system with our fixed threshold with soft thresholding rule.
- Based on the results we recommend to use the decomposition at 6th level. In terms of wavelet families, the best results were obtained for Sym8, db10, coif5, and bior2.8.
- Comparison of thresholding methods:

Wavelet Family	Thresholding Methods Assessment		
	Thresholding method	*RMSE (-)*	*PRD (%)*
Sym8	Heuristic SURE	0.0604	40.3793
	Rigorous SURE	0.0604	40.3770
	Minimax	0.0536	31.8537
	Our Thresholding Method	0.0280	8.6778
Db10	Heuristic SURE	0.0586	38.0758
	Rigorous SURE	0.0586	38.0764
	Minimax	0.0573	36.3373
	Our Thresholding Method	0.0279	8.6397
Coif5	Heuristic SURE	0.0598	39.6386
	Rigorous SURE	0.0598	39.6394
	Minimax	0.0528	30.8616
	Our Thresholding Method	0.0280	8.6548
Bior2.8	Heuristic SURE	0.0591	38.7304
	Rigorous SURE	0.0592	38.7403
	Minimax	0.0507	28.4492
	Our Thresholding Method	0.0286	9.0687

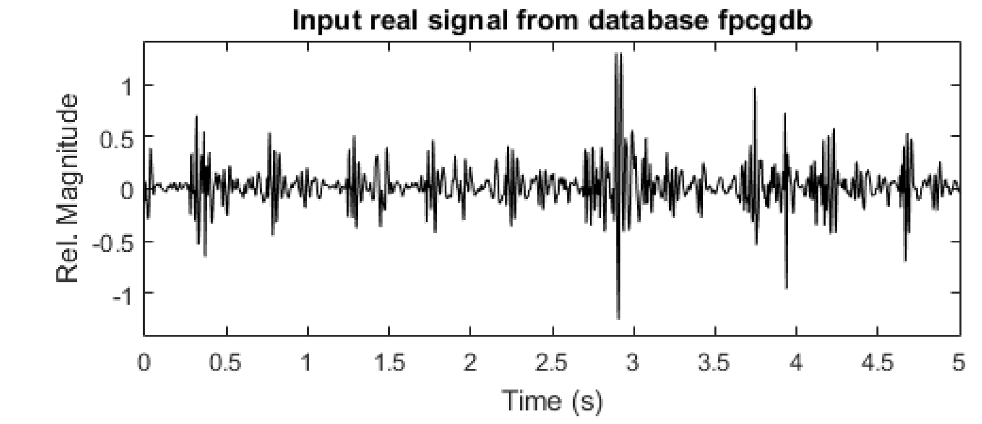
- Example of input aPCG signal, estimated fPCG signal using db10 at 6th level of decomposition, and the ideal (reference) fPCG signal:

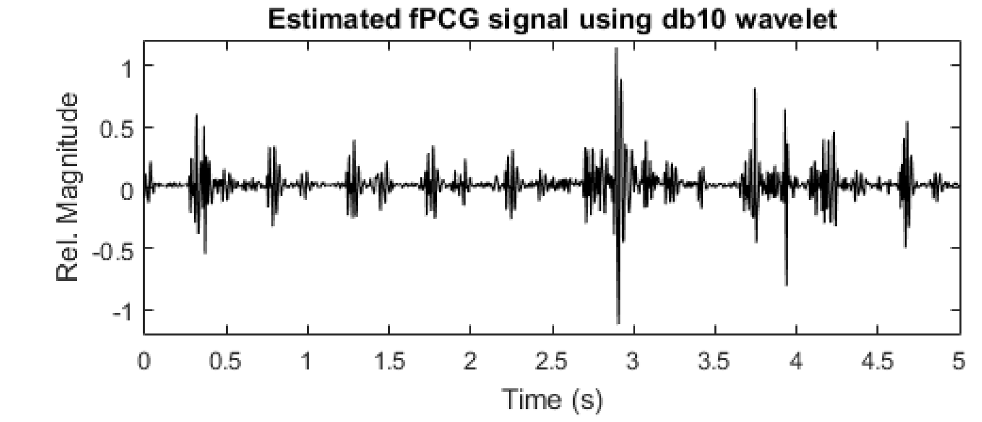


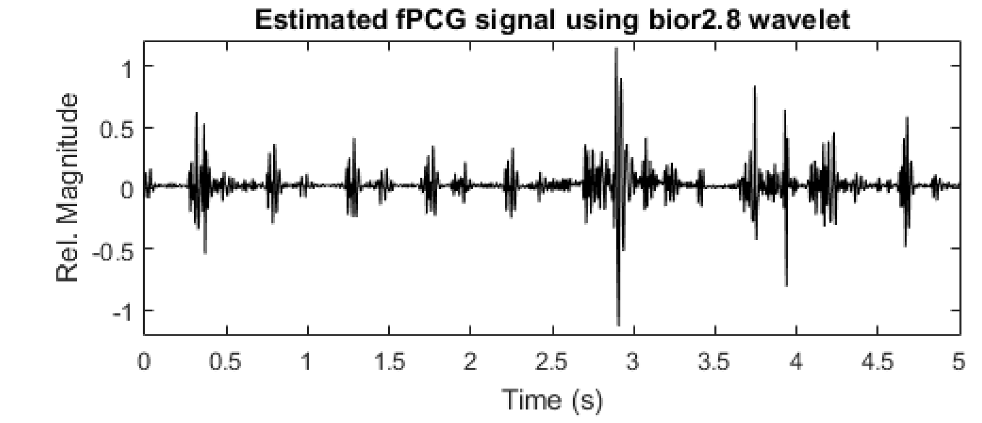




- Finally, we tested the proposed wavelet denoising system on the real data from database *fpcgdb*
- Examples of real aPCG signal from fpcgdb, and denoised signals by means of wavelet sysem using db10 and bior2.8 wavelets, respectively:







Summary

- In this paper, we searched for optimal configuration of the wavelet based denoising system. Based on our experimental results, we conclude that the signal should be decomposed on 6 levels using soft thresholding adjusted for fPCG denoising purposes, i.e. minimizing the detail coefficients at level 1, 5, and 6. Moreover, the most suitable wavelets appear to be Db10 and Bior2.8.
- The denoising system needs to be tested on the larger dataset of both synthetic and real data.
- The tests on the real data revealed that the algorithm is still not able to suppress all of the interference obtained in the abdominal PCG signal.
- Performance of the wavelet based denoising algorithm could be increased by combining it with other noise cancelling system.

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