Performance evaluation of a time-variant filter for ECG signals

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Abstract.

ECG signals are often contaminated by noise from different sources. Noise removal is a complex task due to the non-stationary characteristics of the signal. In this paper we propose a new time-variant filter based on KL expansions. The frequency response of the filter at every time instant of the heartbeat is matched to the estimated local spectrum. A simulation study with ECG signals from the QT database and physiological noise is performed in order to evaluate the filter performance. Two different quality indexes are evaluated: the remaining noise power and the differences on ECG intervals (such as QT and ST intervals) between the original clean signal and the filtered one.

1. Introduction.

ECG signals are often contaminated by noise from different sources such as power line interference and disturbances due to movement of the recording electrodes, like in stress test. In addition, biomedical signals often interfere with one another, e.g., signals owing to muscle contraction, respiration. Noise removal is a complex task because of the non-stationary characteristics of both signals, ECG and noise. In this paper we make use of a recent interpretation of the orthogonal expansions as a time-variant periodic filter [1] whose instantaneous frequency responses depend on the basis functions used in the expansion.

2. Time-variant filter based on orthogonal expansions.

Orthogonal expansions is a very well-known technique for signal analysis. It is based on the decomposition of the signal as a linear combination of simple and elementary functions that results in a time-variant filter [1]. An appropriate choice of the orthogonal functions achieves a signal representation where each coefficient contributes with independent and complementary information. A particular expansion is obtained when the basis functions are the KL functions achieving the maximum signal energy concentration. In this domain signal and noise are most separated. We show in Fig. 1 the equivalent transfer function of KL expansion at different time instants [1] of a heartbeat when using 4 basis functions.

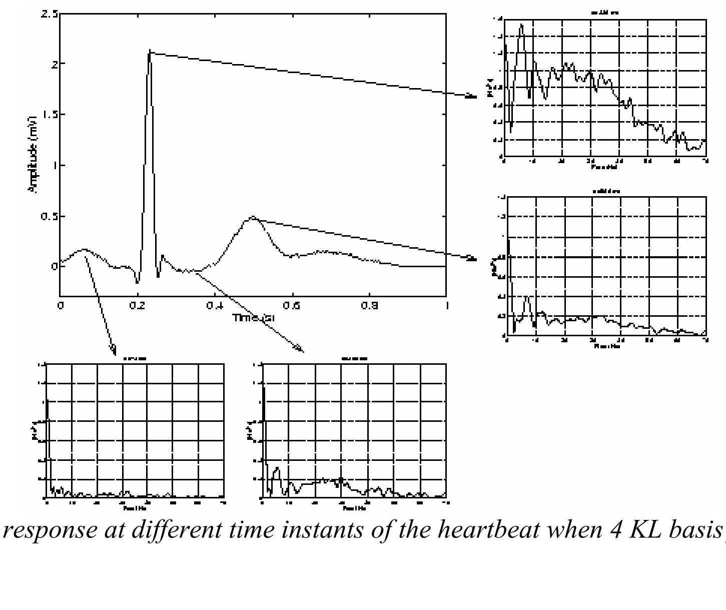

Figure 1. *Frequency response at different time instants of the heartbeat when 4 KL basis functions are used.*

3. Simulation study.

For the simulation study we selected 7 records from the QT database [2] which was developed with the aim to be a reference when validating ECG wave boundaries detectors. A baseline-wandering filter was applied based on cubic spline interpolation. The output signal was assumed the noise free ECG signal. Simulated white Gaussian noise (*wh*) and three records of physiological noise from MIT-BIH database (electrode motion *em*, motion artifact *ma* and baseline wandering *bw*) were added to the original ECG signal. The level of the added noise was much higher than the unavoidable noise present in the original records. We selected three different values of SNR (0, 5 and 10 dB). The noisy signal was the input to a baseline wandering filter based on cubic spline interpolation. Finally the KL expansion was applied. A classical time-invariant low-pass FIR filter was applied as reference (LPF). The order was designed as a 20-order Remez filter, transition-band frequency 25-35 Hz with 20 dB of attenuation. In order to quantify the noise in the ECG signal we used the signal to noise ratio improvement (ΔSNR) between the filtered and the noisy signal. The results given in Table 1 show the higher performance of KL expansions achieving a higher noise reduction in all cases.

Table 1. ΔSNR between the filtered ECG signals and the noisy input signal for all kinds of noise.

SNR	***em***		***ma***		***bw***		***wh***	
	KL exp	**LPF**	**KL exp**	**LPF**	**KL exp**	**LPF**	**KL exp**	**LPF**
10 dB	0.6189	1.0814	0.3232	0.4080	0.1707	0.2028	0.4133	0.5371
5 dB	0.7498	0.9710	0.2653	0.2870	0.0657	0.0793	0.3565	0.4396
0 dB	0.6948	0.9393	0.2156	0.2512	0.0360	0.0387	0.2616	0.4226

The clinical impact of noise in the ECG signal may be also quantified as the differences of automatic wave boundary measurements [3], such as QRS duration, QT and ST intervals, evaluated from the original clean signal and filtered one. Mean values and standard deviation are given in Table 2 for the *em* noise. The differences obtained with KL expansions are lower than for LPF, specially for QRS_{dur} and $ST_{int.}$

Table 2. Mean±std (ms) of automatic waveform boundary differences with clean signal.

	QRS_{dur}			**QT_{int}**			**ST_{int}**		
em	**Noisy**	**KL exp**	**LPF**	**Noisy**	**KL exp**	**LPF**	**Noisy**	**KL exp**	**LPF**
10 dB	-5±24	3±14	-1±17	-85±115	-43±103	-79±113	-18±60	2±24	-21±60
5 dB	-7±28	2±15	-4±20	-105±122	-66±113	-100±121	-33±78	-9±33	-35±78
0 dB	-15±37	-2±20	-11±32	-126±132	-78±119	-120±133	-49±100	6±50	-51±101

4. Conclusions

In this paper we show a preliminary performance evaluation of a time-variant filter based on orthogonal expansions of ECG signals. When the basis functions are the KLT functions we obtain the maximum energy signal concentration. In this case the instantaneous frequency responses of the filter are matched to the local spectra of the heartbeat, giving a superior performance than a classical time-invariant filter in both criteria: noise power and clinical information.

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References

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