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Electrocardiogram Signal Denoising Using a Hybrid Technique

R. Latif, W. Jenkal, A. Toumanari, A. Hatim

***Abstract*—**This paper presents an efficient method of electrocardiogram signal denoising based on a hybrid approach. Two techniques are brought together to create an efficient denoising process. The first is an Adaptive Dual Threshold Filter (ADTF) and the second is the Discrete Wavelet Transform (DWT). The presented approach is based on three steps of denoising, the DWT decomposition, the ADTF step and the highest peaks correction step. This paper presents some application of the approach on some electrocardiogram signals of the MIT-BIH database. The results of these applications are promising compared to other recently published techniques.

***Keywords*—**Hybrid technique, ADTF, DWT, tresholding, ECG signal.

I. Introduction

THE electrocardiogram (ECG), as shown in Fig. 1, represents the electrical activity of the heart. It is an essential element, either in clinical practice or in biomedical analysis. The ECG signal is recorded by electrodes. They detect the tiny electrical changes in the skin resulting from the depolarization of the heart muscle [1].

The ECG signal denoising task is a major challenge for researchers. Several types of noise may disrupt the ECG signal [2]-[4] e.g. the high-frequency noise, which is an internal noise that disturbs the ECG signal. This noise exceeds the vast majority of the frequency band of the normal ECG signal, which varies between 0.5 Hz and 150 Hz. This band contains different internal and external noises. The internal noises are the fluctuations of the human organs on the ECG signal, e.g. the EMG noise. This noise is due to the interference of the ECG and the electromyogram (EMG) signal. The last one represents the electrical activity of the muscles and permits to identify the neuromuscular diseases. The external noises are due to the materials used in the recording of the ECG signal, e.g. the baseline wandering and the power line interferences. The first noise is due to the electrodes. This noise is attested when the patient moves during the recording of the ECG signal. The second noise is due to the influence of the power line frequency of the recording machines (50 or 60 Hz). The ECG signal denoising is an essential and a preliminary task before the analysis of this signal. Due to the different sorts of noise appearing in the ECG signal, the filtering of this signal presents a difficult issue. This difficulty is more appeared in the automatic processing of the ECG signal. Several methods have been developed to deal with the denoising task, such as the DWT [4], the EMD and others [5], [6]. The major disadvantages of the EMD algorithm are the high complexity of the calculations, the mode mixing effect and the stability for small disturbances with infinitesimal noise [7].The DWT is a common technique of the ECG signal processing. Several research works propose the use of different sets of wavelet coefficients to deal with the ECG denoising task [8]. The wavelet coefficients propose several functions close to the morphologies of the ECG signals.

We have proposed recently an efficient method of electrocardiogram ECG signal based on the ADTF approach [9]. This method is inspired from an image denoising technique recently published using an adaptive dual threshold median filter [10].

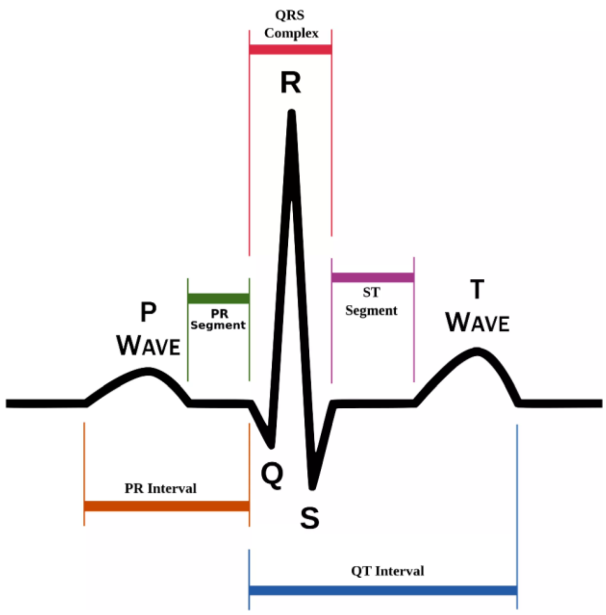

Fig. 1 ECG signal with its features

This research presents an efficient method of cardiac ECG signal denoising based on a hybrid technique. The method consists of two methods namely ADTF and DWT. These two techniques are combined to create an effective denoising process. The method is based on 3 steps of denoising. The first step is the DWT decomposition based on a selected wavelet function. The second step is the ADTF process. And the last

R. Latif, W. Jenkal, and A. Toumanari are with the Laboratory of Systems Engineering and Information Technology (LiSTi) National School of Applied Sciences, Ibn Zohr University Agadir, Morocco (e-mail: r.latif@uiz.ac.ma, w.jenkal@uiz.ac.ma, a.toumanari@uiz.ac.ma).

A. Hatim is with the Department of Industrial and Electrical Engineering National School of Applied Sciences, Ibn Zohr University Agadir, Morocco (e-mail: hatim.anas@gmail.com).

step is the highest peaks correction.

This paper is organized as follows. It starts with a brief introduction of the approach. Next section presents the different steps of the hybrid algorithm. The results and discussion section shows the validation of the application of the method on examples of the cardiac signals ECG from the international MIT-BIH database. The last section concludes this paper.

II. Proposed Method

A. The Baseline Wandering

As mentioned in the previous section, we recently published an efficient approach to deal with the baseline wandering issue. This technique is based on an adaptive mean filter [9]. The mean filter is a common technique in the image processing [10]. However, the results of this technique are a little fuzzy, especially for larger windows. The aim of the proposed technique is based on this note. It proposes an adaptive algorithm that permits to extract the fuzzy representation of the electrocardiogram ECG signal. This representation does not contain major waves of the ECG signal, e.g. the QRS complex. Next, the baseline wandering correction is assured using:

$$Y = X - \eta \quad (1)$$

where Y is the corrected signal, X is the original signal and η is the fuzzy representation of the original signal. Fig. 2 presents an example of the baseline wandering correction using this method.

B. DWT

The DWT is a mathematical method widely used throughout the signal processing. The aim of this processing is to decompose a function of different resolution using high pass filter and low pass filter [8].

Several high pass and low pass coefficients have been developed to give a larger choice among different scales and translations in order to obtain a different sort of signal analysing e.g. Debauchies coefficients (Db), Symlets coefficients (Sym) and Coiflets coefficients [8].

C. ADTF

The basics of the ADTF have been inspired from the dual threshold median method recently published [10]. This technique provides an important solution of the image denoising. In single threshold filters, any pixel with a lower value (e.g. high-pass filter) or higher (e.g. low-pass filter) than the single threshold value is considered as noise. This can increase the possibility of the wrong detection of the noise. In the case of the dual threshold method, the noisy pixels are identified in a relatively narrow range and thus can reduce incorrect detection probability.

In the case of the ECG signal, we have developed an ADTF. An example of the application of this method is illustrated in Fig. 2. The purpose of this filter is to calculate three elements for each window of the ECG signal. Considered parameters are the mean of the window, the higher threshold and the lower threshold. These elements allow elaborating a narrow range in the region of the infected samples and help to denoise these samples correctly.

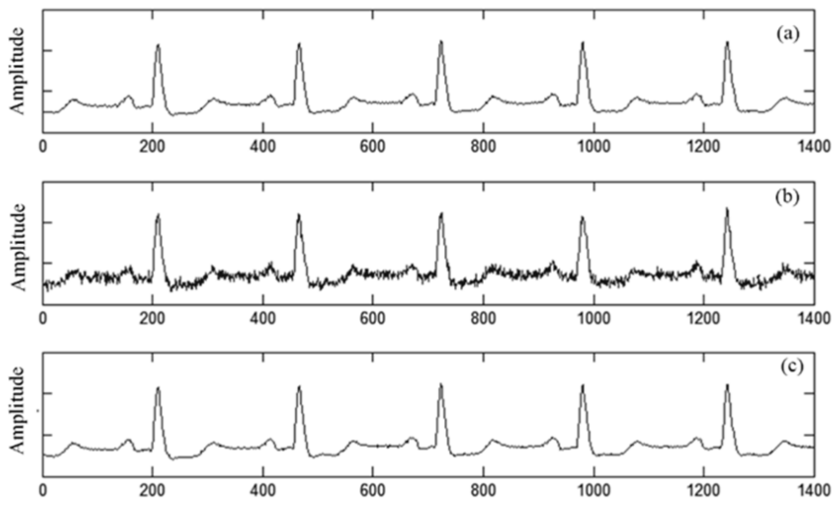

Fig. 2 ADTF denoising process: (a) original signal; (b) infected signal; (c) corrected signal

D. Hybrid Algorithm: ADTF-DWT

The presented algorithm is based on three steps of denoising. This process permits to decrease successively the noises in the ECG signal.

Step1. This step is based on the DWT. This transform decomposes the ECG signal at different frequency bands. The wavelet coefficients used in this method are the Debauchies 6 coefficients (db6). These coefficients show best results compared to others in this method. This is due to the similarity of the db6 with different morphologies of the ECG signal. The aim of this step is to eliminate the high density of noises presented in the details of the ECG decomposition.

Step2. The second step of the method is based on the application of the ADTF in the resulted signal of the previous step.

Step3. The aim of this step is to include a correcting stage of the highest peaks in the ECG signal. These peaks present some important waves of the analysed signal which can be infected by the previous step.

III. Results and Discussion

The proposed approach has been tested on some of the MIT-BIH database signals. This database is widely used in different related research works [11]. The MIT-BIH is proposed by the international database Physionet.

Fig. 3 shows an example of the application of the hybrid approach in the MIT-BIH signal n°101. In this case, the high frequency noises had been simulated using a White Gaussian Noise level (WGN) of 10dB. As shown in this figure, the approach provides an important solution to deal with the denoising task.

Gathering between the two methods takes profit from the advantages of both them. We added a step to recover precisely the ECG peaks also. The noise was deleted without great loss in the original signal. This makes the compression step very efficient. In fact the compression step is the next after denoising. The noise introduces an important variation which makes very difficult the use of some efficient compression algorithm like delta coding, DWT... The introduced filtering technique cost is higher. The computational complexity and latency of the proposed algorithm can be easily overtaken by the recent embedded processors.

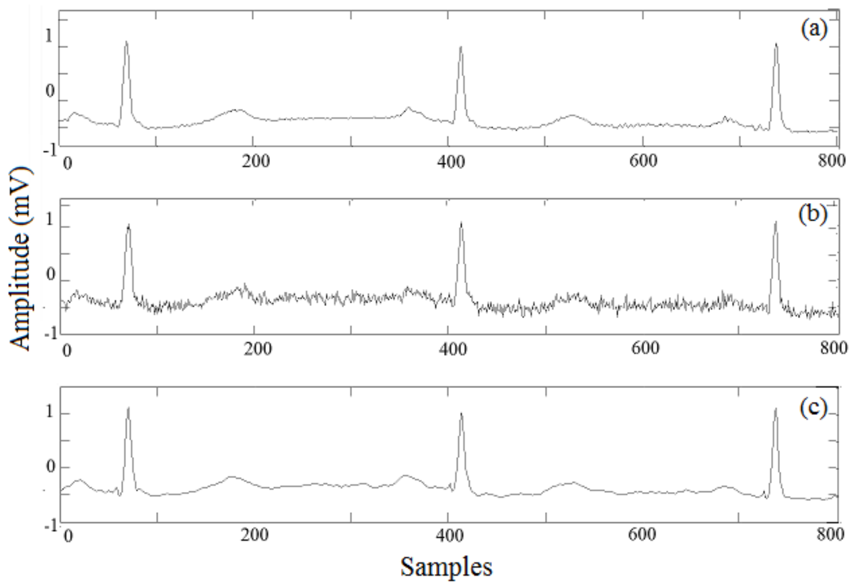

Fig. 3 ECG signal denoising (10dB of WGN): (a) original signal; (b) infected signal; (c) corrected signal

TABLE I
SNRimp Comparison

MIT-BIH	ADWT	MABWT	ADTF-DWT
100	9.40	7.80	9.70
101	9.09	6.90	10.23
115	7.19	7.80	9.45
122	7.86	6.90	8.07

In this paper, we presented an efficient approach that gathers the adaptive dual threshold filter, which is proposed recently [9], and the DWT. The aim of this technique is to bring together the advantages of these methods in order to improve the filtering of the electrocardiogram ECG signals.

Table I presents a statistical comparison between the presented method and the ADWT method as well as the MABWT as presented in [11]. The comparison has been done using the statistical parameter SNRimp (signal to noise ration improvement). In this case, the high frequency noises had been simulated using a WGN level of 5dB. The comparison results illustrated in Table I show that the approach in this work presents the best results compared to the works published in [11]. This makes it possible to observe the high performance of the proposed method.

IV. Conclusion

In this paper, we presented an efficient approach to denoise cardiac signals ECG based on a hybrid technique using the methods namely ADTF and DWT. The aim of this technique is to bring together the advantages of these methods in order to ameliorate the efficiency of the ECG signal denoising task. The results allow concluding the high performances of the proposed approaches compared to recently published methods.

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