Revealing and evaluating the influence of filters position in cascaded filter: application on the ECG de-noising performance disparity

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ABSTRACT

In this paper, a new optimization on windowing technique based on finite impulse response (FIR) filters is proposed for revealing and evaluating the Influence of filters position in cascaded filter tested on the ECG signal de-noising. baseline wander (BLW), power line interference (PLI) and electromyography (EMG) noises are gettingremoved. The performance of the adopted method is evaluated on the PTB diagnostic database. Subsequently, the comparisons are based on signal to noise ratio (SNR) improvement and mean square error (MSE) minimization. Where the Rectangular, and Kaiser windows have been used for the more potent performances. The disparity average (DA) of SNR values is detected; in both Kaiser and Rectangular windows are assessed by ±0.38046dB and ±0.70278dB respectively, while the MSE values were constant. The excellent configuration or filters position (H-B-L) of the filtration system is selected according to high measurements of SNR and low MSE too, to de-noise the ECG signals. First of all, this applied approach has led to 31.30 dB SNR improvement with MSE minimization of 26. 43%. This means that there is a significant contribution to improving the field of filtration.

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1. INTRODUCTION

Etiology of electrocardiogram (ECG) signal allows physicians to understand physical and pathological conditions of the ECG diagnosis. Generally, the noises can hide and corrupt important information from the beginning of heartbeat monitoring records. Some frequency noises have existed in the frequency band of the ECG signal, and the ECG signal will often get distorted, which limit the extraction of useful information from it. The instrumentation noise referred to the noise originated in the data collection device, the electronic noise which is a specific kind of the instrumentation noise. This kind of noise is referred to as flicker noise which overlaps in the frequency domain with electromyography (EMG) noise. Therefore, filtering the EMG noise will, in turn, reduce these flickers [1]. Other noise sources affecting the ECG signal such as channel noise, electrode contact noise, motion artefacts'….etc.

The main noises addressed in this paper are classified into three main types: electromyography noise, power line interference (PLI) and Baseline Wander (BLW), which themselves occupy three frequency bands: high, medium and low frequency respectively:

a) The electromyography (EMG) noise; which emerges because of the contraction of muscles other than cardiac muscles [2] and is assumed to be transient bursts of zero mean bands limited Gaussian Noise [3]. It is overlapped with the ECG signal in the moment of heart electrical activity recording, including the amplitude of this kind of noise; it is random and could be reasonably approximated by a Gaussian function in the range of 0 to 100mV. Hence the ECG signal's amplitude ranges from 0.1 to 5 mV. Therefore, EMG noise and ECG signals participate in the frequency spectrum with significant parts of energy [1]. So, the EMG noise can be removed by using a low pass filter (LPF).
b) The power line interference (PLI); mostly happened due to unsuitable grounding of the ECG device. This latter affects the quality and detailed features of the signal which can be critical for signal processing because these features are rich sources of information. It operates in medium frequency, i.e. (50Hz / 60Hz). This noise can be suppressed by a band stop filter (BSF).
c) The last noise is Baseline wanders (BLW); body actions, respiration, sweat, and improper electrode connections are the main sources of this noise. According to Nyquist's rule, its frequency range is usually between (0.1Hz-0.5Hz), its low frequency, can be eliminated using high pass filter (HPF).

As ECG and some noises share the same frequency, the best de-noising technique is the one that provides the best trade-off in terms of minimal wastage of information and interesting level of noise elimination [4]. In the context of this issue, studies covering ECG signals are largely listed in various states of art, specific literature and in several methodologies of de-noising ECG signals. A lot of algorithms have been proposed for ECG signal de-noising. Some of them are derived from using Savitzky-Golay filter for the pre-processing stage such as in [5], discrete wavelet transforms (DWT) in [6-8], adaptive filter in [3, 9-15], and digital filter in [2, 16-20]. Where, in [21], Ge Wang et al. proposed a novel ECG signal de-noising algorithm based on the deep factor analysis for eliminating a Gaussian-distribution noise signal. In [22], systematic reviews of deep learning (deep neural network) methods have been used in various ECG analytics tasks are presented, by analyzing the papers that were published since 10 years ago. A. k. Verma et al. proposed the alexander fractional differential window (AFDW) filter for ECG signal de-noising and achieved better noise reduction results [23]. To sum up, it can be said that each of these algorithms or techniques focus on deleting unwanted signals and improving the ECG signal quality. Hence, filtering is the first step in terms of the ECG signal processing, i.e. no step can be initiated before passing through this stage.

To be consistent with discussions about the summary of relevant works, and addressing of the cascaded digital FIR filter is given for eliminating multi-levels of noises, as presented in the [2], a cascaded three sets of the Kaiser-window function based FIR filters were designed for suppressing the BLW, 50/60Hz and EMG noises from a noisy ECG signal. Hence, different ECG signals from MIT-BIH normal sinus rhythm (NSR), ECG ID databases are considered for the simulation. The performance measures are related to SNR, MSE and power spectral density (PSD). Where, in [19], by considering the best SNR resulted from different windowing techniques, cascaded FIR filters have been carried out as FIR LPF hamming, FIR HPF Rectangular and FIR Notch Rectangular combination for removing the same noises from ECG signal. The ECG samples have been extracted from the MIT-BIH database. The authors in [24] proposed four combinations of cascaded filters were used for removing the undesired frequencies from a noisy ECG signal. Where FIR HPF was designed by Blackman window, Adaptive Filter was designed by NLMS algorithm, Notch Filter (50Hz) and low pass IIR filter was designed by the Elliptic approximation method. The ECG samples have been accessed from the MIT-BIH Arrhythmia Database. The high performance resulted from SNR and PSD parameters have been compared with the results obtained in [2], as shown in the Table 3.

As brut ECG signal contaminating by multi-levels of noises, a cascaded filter can remove different noises depending on desired frequencies, which involves many steps such as shown in the Figure 1. Therefore, an FIR filter can be designed with different windowing methods. But there is an important remark to the point which concerns the fact that the arrangement of filters position has not been covered in the above mentioned algorithms, this problem that we checked and analyzed in this study through the few papers of this manuscript. However, the following sections will be showing the detail of the idea of revealing and evaluating the Influence of filters position in the cascaded filter, in which that's tested on the ECG signal de-noising with three levels of courant noises. The use of this issue should not be random due to its impact on the quality of the resulting signal. As a resolution, the filters' arrangement in the cascaded filter has been affected by the parameters and the combinations of the filtration systems i.e. the filters arrangement plays a vital role significantly improving the cascaded filter performance in the task of signals filtration. This latter idea constitutes the originality in this contribution. So, this study aimed to characterize each type of windows (adjustable or fixed window) such as Kaiser and Rectangular windows of various SNR levels (0 to 10 dB) and to assess the effects of the filter position arrangement on various ECG signals. Nevertheless, this contribution provided important effectiveness and superb potential in the design of the filters.

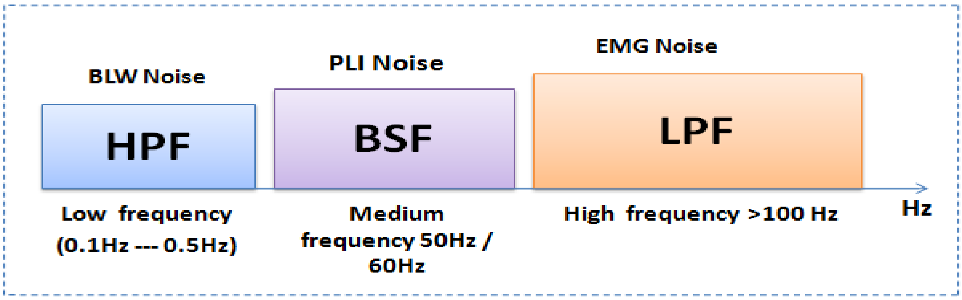

Figure 1. Different types of noises compatible with various frequency bands

2. METHODOLOGY

Finite impulse response (FIR) filters are the foremost basic digital signal processing system parts. It's, at any rate, the frequency with a strictly linear phase. There is no input to output feedback that could be a stable system. On the other hand, the characteristics of distributed arithmetic (DA) algorithm are preferred as a result of greatly scaled back hardware size utilization which ends up into high speed execution [17]. Finite impulse response filters are also recognized as non-recursive digital filters; these filters are often used in digital signal processing owing to its flexibility. However, there are three main methods for FIR filter design namely:

a) Optimal filter design method.
b) The frequency sampling technique.
c) The windowing method.

The FIR filter can be designed by different windowing method. Where, there are two window kinds, namely: fixed and adjustable windows. There are many other methods used for designing FIR filter such as Equiripple, least square, maximally flat instead of the windowing method, regarding the ECG de-noising problem [16], many studies have been made to prepare the combination of various types of digital filters, such as shown in the Figure1.

The Figure 1, Shows the different types of noises compatible with various appropriate frequency bands based on digital filter types respectively. Moreover, most of the previous works have adopted a window method to design the cascading FIR filters. To the best of our knowledge, there is no single study that proves or disapproves the impact of filters position on the performance of the cascading filter. To address this issue, a new proposed approach to prove the impact of the filters arrangement with employe the Kaiser and Rectangular window distributed on the cascading FIR filter, i.e. select the accuracy configuration that gives the best outputs performances of SNR and MSE for each filter position in each window.

The Kaiser and Rectangular windows selected from FDA Tools, since they're largely used in more than one work related to the filtering of the ECG signal and their performance as it was appearing in [2] and [25]. This procedure will be applying it to each type of digital FIR filter such as shown in Figure 2. On one hand, the SNR and MSE performances of each configuration produced by changing the filter positions, which are used to form the cascading FIR filter, we are compared with the results of Rectangular and Kaiser windows performances.

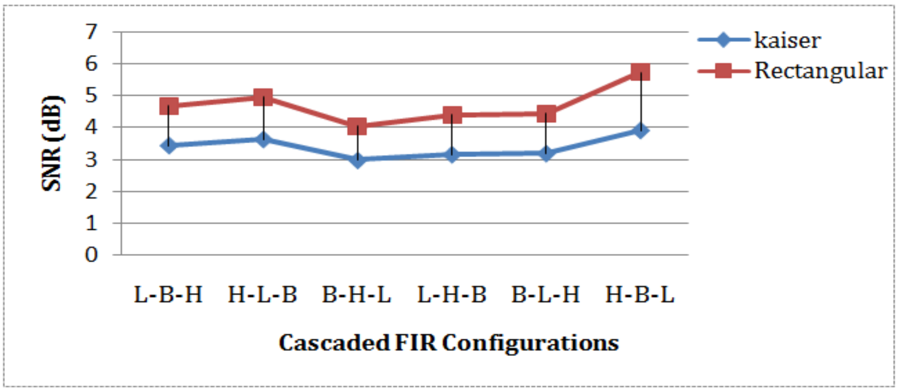

Figure 2. The kaiser and rectangular performances

The cascaded filters are taken with a fixed order of (360), because this approach is limited to studying the change in the system performance by changing the positions of its constituent filters, and this is what makes the observed stationary measurements in all possible attempts. However, the method based on estimating the disparity of the changed value in SNR and MSE performances, resulting from the output of cascade filter bloc design, will be produced six possible patterns of cascade filter, i.e. it's represented the six cascaded filter configurations for each mentioned window as shown in theTable 1, i.e. The two windows from FDA Tools, are tested with the filters, and the six cascaded filter configurations are obtained.

According to the condition of SNR and MSE measurements, the disparity average (DA) is detected from changing values of filters position patterns; will be investigating the best filters position and the convenient window, applied to achieve the task of filtering the noisy ECG signals in different cases. The position of the three filters that justified the best configuration had to achieve a more potent in the quality and accuracy appearance of the ECG signal.

On the other hand, more than 10recordedsamples used in advance, by taking into account more than one diagnosis of different heart diseases [26]. Hence, the results are inserted in theTable 2 in which showing the estimation of the SNR and MSE obtained from the final phase of eliminating the predominant interferences of the ECG signal before and after filtration.

Figure 3 illustrates a detailed work plan that lists the steps that have been identified to reach the desired results. For clarification only, here we find the term moving filter (cascaded FIR filter), which means that the filters are repositioned at the same time inside the cascaded filter every time from making the necessary measurements. The following steps illustrate the algorithm procedure.

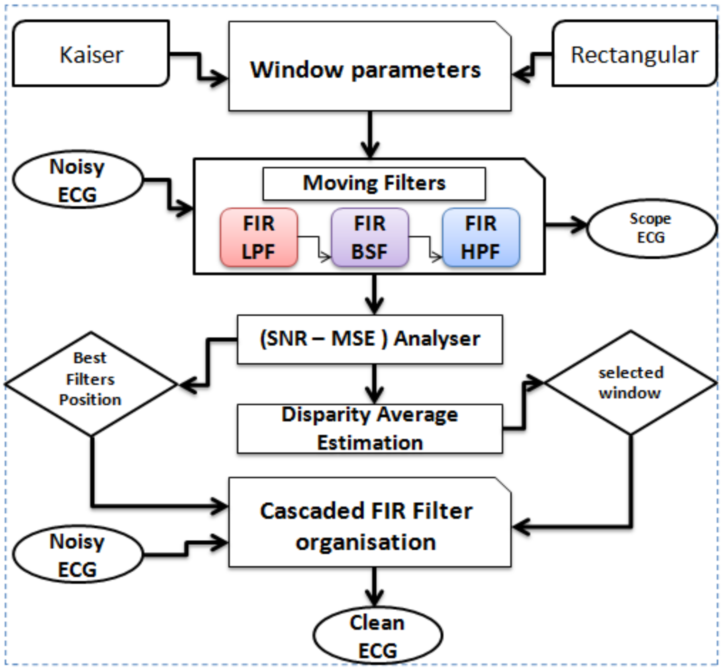

Figure 3. Diagram of the proposed method

Algorithm Pre-Processing Captured ECG signal
Input: Noisy ECG signal *E* Input.
Output: De-noising ECG *E* Output.
Issue: an investigation into the change value of SNR end MSE performances in terms of changing the position of the filters.
1: Load *E* Input.
2: Initialization of each filter by choosing orders, cut-off frequency and simple frequency in FDA Tools.
3: Filtering *E* Input signal by using (Kaiser window, then Rectangular window) available in FDA Tools, and changing the position of the filters in each time.
4: Computing and comparing the *E* Output according to SNR and MSE parameters forthe position of each cascaded filter.

5: Disparity Average estimation of any change in the SNR or MSE values and comparing them for both windows.
6: Using the best position of filters and the best window to improving the ECG signal in all cases in general.

Normal and abnormal ECG signals are collected from the Physiobank database, which is freely available on-line at [26], where could find many previously recorded ECG patterns such as a text header file, binary annotated file, and binary data signal file. The recorded signals have been retrieved from Physiobank ATM - export signals as (mat) format to taken experiment, manipulation and implement using MATLAB and SIMULINK environments. As a proof of concept of this study, the four following subsections included in completing the results of the experimentations.

2.1. Evaluation of PTB diagnosis ECG database

With MATLAB, SIMULINK version 8.2.0.701(2013b) 64 bit for windows 7, operating system OS 64bits; the project has been achieved by retrieving the raw ECG signal from a physiobank (PTB diagnosis ECG database). The records were digitized at 1000 samples per second per channel with 16 bits resolution (14 bits for ECGs, 01 bit for respiration effect and 01 bit for line voltage effect) over ±16 mV ranged of (0 to 65535) [26], i.e. 32768 which is the midpoint of resolution that is worth 0 mV. The ECG samples data file from the PTB database is extracted and considered as original ECG signal with low and Medium frequency noises. Experimentally the same samples data employees for identifying the performance levels of proposed work, such as shown in Table 2.

2.2. SNR and MSE parameters

ECG Signal de-noising approaches are usually estimated by the signal to noise ratio (SNR) on dB and mean square error (MSE) parameters. Furthermore, these parameters have the ability to know how close the de-noised signal is in the original signal assessment.

$$SNR = 10\log_{10}\left[\frac{\sum_{n=1}^{N} x(n)^2}{\sum_{n=1}^{N}(y(n)-x(n))^2}\right] \quad (1)$$

$$MSE = \frac{1}{N}\sum_{n=1}^{N}(y(n)-x(n))^2 \quad (2)$$

As shown in (2) and (3) are used to calculate the SNR on dB and MSE of the filtered signal respectively, where, x(n) is the original ECG input signal, y(n) is the output de-noised ECG signal of digital filters, and N is the sampling points of ECG signals [27]. Hence the better de-noising method should have a higher SNR and a lower MSE.

2.3. Digital FIR filter

The response of such a filter to an impulse is composed of a finite sequence of M+1 sample, where M is the filter order. Hence, the output Y(m) of an FIR filter is a function only of the input signal X(m) and bk are the filter coefficients [28]. The impulse response of a linear-phase FIR filter has even or odd symmetry, which can be exploited to reduce the number of multipliers [29].

For digital FIR filters, a (compiler 5.0 block set) are used such as digital filters in our simulation experiments, the filters are applied with a fixed order, a sampling frequency of (360 Hz >= 2*(original ECG signal)) and cut-off frequency selected according to the undesired noise frequency. So, these materials, equipment and Simulation methods are combined to achieve our main aims, and fill in the results of the experiment noted in the following tables, in the next section. A digital FIR filter of M order has the transfer function can be described by:

$$Y(m) = \sum_{k=0}^{M} b_k x(m-k) \quad (3)$$

2.4. FDA Tools and window function

The Filter Design and Analysis (FDA) is a very important tool to create filter transactions. The options available depend on the specific filter design method [30]. There are two types of window functions described by an adjustable window and fixed window [29]. The adjustable window has been set up with one or more parameters, in which, the Kaiser window was adopted with “Beta” parameter β = 0.5 in this approach.

On the other hand, the FIR Equiripple and FIR window design methods have settable options. For FIR Equiripple, the option is a density factor. For FIR window the options are Scale Pass-band, window selection, and for the following windows, a settable parameter [30].

3. RESULTS EVALUATIONAND DISCUSSION

3.1. ECG De-noising performance based on filters positions with kaiser and rectangular windows

Within the scope of knowledge from our proposed method experiments, including that the process of noises disposal, depends on several factors that directly affect the filter results and the quality of the accompanying signals. These issues can be explained in the following points: How to select the position of each filter in the combination of cascaded filter? I.e. which one among these filters should be the first, intermediate or last to combine them? Then, how to determine the cut-off frequency bands with appropriate order for each filter? And the sorts of windows which are used for configuring the filter or any other technique for filtering the signals?

Table 1shows the results obtained from the final phase of eliminating the predominant interferences of the ECG signal. However, by applying all possible experiments on the three filters positions which are used for the serial system representing the cascaded FIR filter. The outputs SNR and MSE parameters given by each configuration (position) are compared in Kaiser then Rectangular window. Hence, the test of various SNR levels are concentrated (2 to 6 dB), where the best SNR levels are trapped nearly like 3.40< SNR<3.90 dB in Kaiser window and 4.95< SNR< 5.75 in Rectangular window.

Table 1. The results of the de-noising performance of several positions using SNR and MSE parameters

Filters	Kaiser		Rectangular	
positions	SNR	MSE	SNR	MSE
L-B-H	03.4351	0.0100	04.6830	0.0098
H-L-B	03.6239	0.0100	04.9433	0.0098
B-H-L	02.9798	0.0100	04.0432	0.0098
L-H-B	03.1553	0.0100	04.3981	0.0098
B-L-H	03.1891	0.0100	04.4268	0.0098
H-B-L	03.8996	0.0100	05.7223	0.0098
DA	±0.38046	0	±0.70278	0

The disparity average of SNR values in Kaiser and Rectangular windows are respectively estimated by ±0.38046 dB and ±0.70278 dB. These values have been extracted to identify the difference between each these windows. Moreover, which gets up the task of choosing the right window is possible.

These values may be small but can affect the quality of the process and the appearance of the morphology of ECG signals as shown in the Figure 4 and 5. However, the MSE performances were remained stable in both windows, as derived from improved configurations respectively. Thus, observations are admitted the (HPF-BSF-LPF) configuration or H-B-L position as the best among all positions; moreover, this structure is achieving the desired accuracy to improve the quality of ECG signals, through the above-mentioned rules of maximum SNR and minimum MSE. However, such as found in the following table the results achieved from this composition after generalizing the validity of its performance on many signals with different sources and patterns.

You can look at the points represented in the graphical curve of the performance of the used windows. By checking what is shown, the values of SNR are constantly changing in each configuration that has been applied. As the values were fairly consistent, except that the Rectangular as a fixed window, it achieved a noticeable rise in the H-B-L configuration, and this supports what was stated in the comment about Table 1. From here it will be better to contain the variables that can be examined through ANOVA application.

3.2. The ANOVA results

To check the validity of results, the one-way analysis of variance (ANOVA) was also employed for analyzing the effects of filters position with the tow selected window types at various SNR values on ECG de-noising system. The ANOVA results ($F = 22.993$, $P = 0.000$) indicate that the filters positions arrangement of the cascaded system at various ECG signals has significant differences.

3.3. ECG De-noising based on H-B-L configuration

The Figure 4 shows the steps of the cascaded FIR filter of our proposed method, which the signal passes during noises cancelling. Furthermore, the PTB database records contain clean ECG signals grouped with respiration and 50/60 Hz effects, the WGN has been added to form a noisy ECG signal by three major noises such as shown in the Figure 5.

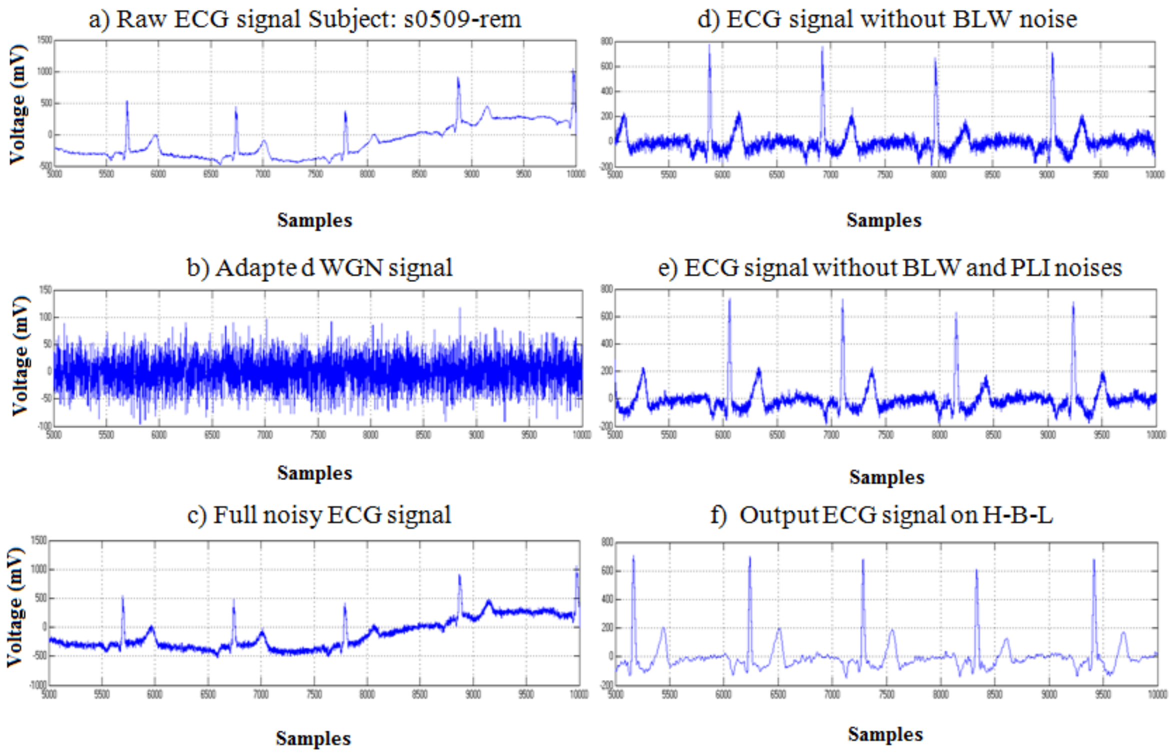

Figure 4. Steps of de-noising ECG signal using the H-B-L configuration

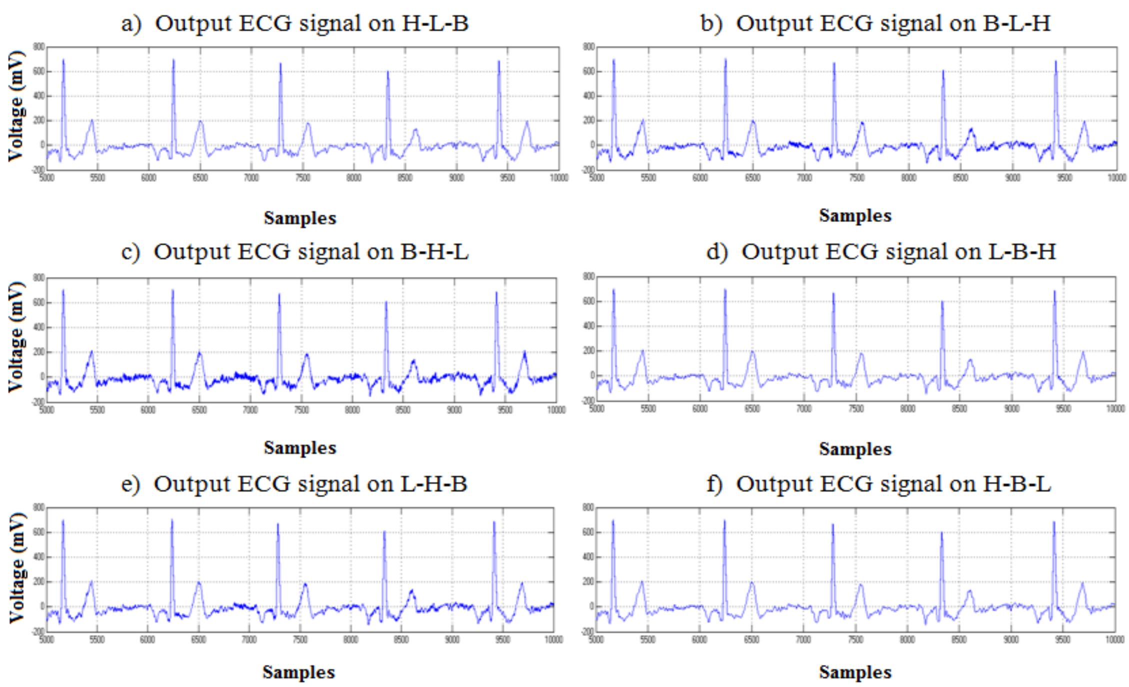

Figure 5. The output signals resulted from the cascaded filter with different configurations

The H-B-L configuration to be proved a successful noise removal procedure while preserving the morphology of the ECG signals. However, you can check the signal as it goes through the following filtering steps. Where, a) Raw (original) ECG signal was recorded for Patient N^o 271 in the PTB database; this indication is accompanied by BLW and PLI noises, which have been diagnosed with the disease of Myocarditis, and that's due to additional diagnoses of Arterial Hypertension [26].b) WGN corrupted raw ECG signal at an SNR of -27.42 dB adjusted to achieve SNR levels, it is used as the muscles' contraction effect source, i.e. the effect of EMG noise [31]. c) The raw signal mixed with WGN (full noisy ECG signal), where it passes through the next three phases of filtration in tags as shown in the following steps. d, e and f. d) The signal resulting from the first filter HPF is free from BLW noise, where it became in accordance with the axis line 0.e) The signal resulting from the second filter BSF is free of BLW and PLI (50/60Hz) frequency noises, where it should be as input for the next stage of the de-noising task. f)The signal resulted from the third filter LPF and the EMG noise removed with the other noises (de-noised ECG signal).

3.4. ECG De-noising based the comparison the morphologies of deferent configurations

By applying the deferent configurations, in which a noticeable difference created out on the ECG signal morphology. The signals generated by this work show the difference between the cases. Where the resulted ECG signal was presented the real signal waveform. Hence, a),b),c),d),e) and f) are illustrating the morphology of the cardiac cycles; with different thickness in each of them, but f) It is the best due to the excellent configuration (H-B-L). However, the resulting signal preserves the ECG morphology. Hence, in this type of studied data, we found that the P wave was inverted (negative) [32] and this is due to the diagnostic status of the patient from which the data are drawn.

3.5. Confirmation on other ECGs diagnostic class

Table 2 shows the results obtained from the conformations of our proposed approach using the (H-B-L) configuration with Rectangular window. The records shown in this table extracted from the PTB diagnostic database, within the header (.hea) files of most of these ECG records contain a detailed clinical summary, including diagnosis, age, gender, and data on medical history, hospital medication and interventions [26]. The SNR_1 and MSE_1 represent the estimations of ECG's records before filtration and The SNR_2 and MSE_2 represent the estimations after filtration.

Table 2. Confirmation effects of the de-noising performance of the proposed method for different diseases in PTB diagnostic database

Diagnostic class	PTB db	SNR_1	SNR_2	MSE_1	MSE_2	Effecton waveform
Myocardialinfarction	S0175_rem	5.1806	19.8621	0.0092	0.0072	Improved signal
	S0010_rem	-5.8159	25.4414	0.0087	0.0064	Improved signal
Cardiomyopathy	S0392 lrem	-3.0643	13.0686	0.0100	0.0087	Improved signal
	S0200_rem	-2.3932	05.6751	0.0097	0.0092	Improved signal
Heart failure	S0023_rem	-10.1776	06.7796	0.0099	0.0093	Improved signal
	S0183_rem	-0.3146	12.3121	0.0101	0.0089	Improved signal
Bundlebranch block	S0441_rem	-7.1860	23.0859	0.0111	0.0088	Improved signal
	S0429_rem	-1.9127	09.3006	0.0107	0.0098	Improved signal
Dysrhythmia	S0018_rem	-3.3716	11.2205	0.0105	0.0094	Improved signal
	S0169_rem	-3.1767	03.4769	0.0097	0.0093	Improved signal
Myocardialhypertrophy	S0390_rem	-3.2867	06.7679	0.0097	0.0098	Improved signal
	S0434_rem	-11.3830	07.7710	0.0095	0.0088	Improved signal
Valvular heart disease	S0030_rem	-8.7241	18.8872	0.0103	0.0084	Improved signal
	S0199_rem	-8.4363	10.4248	0.0093	0.0083	Improved signal
Myocarditis	S0509_rem	01.5051	05.7223	0.0103	0.0098	Improved signal
	S0510_rem	-5.6683	04.4123	0.0102	0.0098	Improved signal
Healthy controls	S0545_rem	-5.4696	01.9337	0.0104	0.0103	Improved signal
	S0500_rem	01.4517	01.8169	0.0107	0.0105	Improved signal

With this proposed approach is applied by testing the windows with the filters, under the condition of maximum SNR and minimum MSE, the best performance is achieved in each diagnostic record class and detect improved ECG signals. In the context of this approach, the experiments have been recognizing that it eliminates the problem of determining the appropriateness of any filter to get read the undesired frequencies from any raw signal. Therefore, the selection of filters in cascaded FIR filter combination should not be random, due to its impact on the quality of the resulting signal. Each combination of cascaded FIR filter has its performance. This is not limited to improving the quality of the ECG signal solely, but rather to apply this technique to another type of signals.

3.6. Comparison of the proposed approach with existing works

The high performance obtained in this optimization has been compared with the existed papers, [2] and [24]. Hence, this comparison contains four types of ECG database from the Physiobank ATM. So, the significant SNR improvement and MSE minimization resulted from the different proposed cascade filter designs, are illustrated in the Table 3.

Firstly, this study deals with the problem of positioning filters in the serial filter, mainly due to the lack of awareness of their importance in previous works. This method of selecting the best configuration of the filter used to remove noise has achieved fairly impressive success in terms of the quality of performance and the appearance of the resulting signal in general. Secondly, after an in-depth analysis of the data obtained, we reach that this task gives valuable and additive contribution in the field of successive filtering. Finally, the algorithm preserves useful information while removing noises from the ECG signal with the performance of noise reduction is outstanding.

Table 3. Comparison of proposed cascaded FIR filter design with existing works

Author name	Physiobank ATM database	SNR improvement after filtering(dB)	MSE minimization (%)
Patro et al.,2015 [2]	MIT-BIH NSR DATA	4.14	21.81
	MIT-BIH ECG ID DATA	2.47	35.30
Navdeep et al.,2019 [24]	MIT-BIH Arrhythmia	7.75	-
Present work	PTB diagnostic ECG database	31.2573	26.43

4. CONCLUSION

Every earlier research may agree that the cascaded filter can be applied as a design for suppressing multi-noises from ECG signals, but if it can save the morphology of the signal. With the deep study, the capability of the proposed optimization technique was identified and evaluated using the potential of SNR and MSE parameters. Therefore, the overall results obtained show that selected filters are a reliable technique to be used in recognizing the various effects on cascaded filter design. The experimental results are shown that Rectangular window is more potent than the Kaiser window. Hence, the best SNR levels are trapped nearly like 3.40 dB < SNR< 3.90 dB in Kaiser window and 4.95 dB < SNR< 5.75 dB in Rectangular window. Hence, the disparity average of SNR values, in Kaiser and Rectangular windows are respectively estimated by ±0.38046 dB and ±0.70278 dB. However, the MSE performances have remained stable or the difference is very little in both. On the other hand, this applied approach has led to 31.30 dB SNR improvement with MSE minimization of 26.43%. So, the objectives of this study have been successfully achieved with the desired expectations, even by using more than ECG's signal with incorporating different diagnostic classes. The excellent configuration or filters position (H-B-L) was proved a successful de-noising action with saving the morphology of ECG signals. This optimization will certainly provide an efficient additional tool in ECG signal analysis, where the position of the filter plays a vital role significantly improving the cascaded filter performance. Moreover, an extension to implementing this method in specific hardware co-simulation environments is recommended.

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