ECG De-noising based on the Selection of Cascaded FIR Filter Configuration

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Abstract – **In this paper, cascaded window based digital FIR filter design is presented. Three sets of FIR filters are adopted to remove noises from the ECG (Electrocardiogram) signal. These noises can be classified into three main types: electromyography (EMG), Power Line Interference (PLI) and Baseline Wander (BLW), which themselves occupy three frequency bands: high, medium and low frequency respectively. This contribution is intended to improve the ECG signal's quality. The resulting performance is evaluated on the (Physikalisch-Technische Bundesanstalt) (PTB) diagnostic database. Two stages are considered for this task; the performance of one FIR filter is tested in three types separately; High Pass Filter (HPF), Band Stop Filter (BSF) then Low Pass Filter (LPF). The comparisons are based on Signal to Noise Ratio (SNR) improvement and Mean Square Error (MSE) minimization. Rectangular, Kaiser and Taylor windows have been selected in order to obtain the more potent performance. In the second stage, the same selected windows are applied on three cascaded FIR filters (HPF-BSF-LPF) leading to 27 configurations. The best resulting configuration is selected to de-noise the ECG signals. The applied approach has led to 31.30 dB SNR improvement with MSE minimization of 26. 43%.**

Keywords – **ECG, FIR filter, Noise, PTB database, SNR, MSE, Cascade, Window.**

I. Introduction

Electrocardiogram (ECG) is a very important biomedical signal and the processing of the ECG signal is not only recommended but vital. However, that ECG signal is corrupted with different noises inside and outside its frequency band (0.01-128 Hz). Hence, extracting useful information from the distorted signal is a difficult task, because the corruption signal is created due to the biological sources such as human body and ecological sources such as data collection device [1]. For example, 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 EMG (electromyography) noise. Therefore, filtering the EMG noise will in turn reduce these flickers [2]. There are other noise sources which affect the ECG signal such as channel noise, electrode contact noise, motion artefacts, etc.

The main noises addressed in this paper are EMG noise, power line interference noise and baseline drift noise [3]. The first type is EMG noise which emerges because of the contraction of muscles other than cardiac muscles [4] and is assumed to be transient bursts of zero mean bands limited Gaussian noise [5]. 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 [2]. EMG noise operates in the high frequency range, i.e. (>100 Hz), so it can be removed by using low pass filter (LPF).

The second noise is power line interference (PLI), mostly happened due to unsuitable grounding of the ECG device. This noise 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 the band stop filter (BSF).

The third noise is the 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 a high pass filter (HPF). De-noising ECG signal is a chain of steps taken in order to decontaminate the original ECG signal from noise.

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 [6].

The rest of this paper is organized into seven sections. Section II and III present the related work and discuss the theoretical background of this work. Section IV details the proposed and developed method. Section V explains the experiments and simulation technique. Results and discussions are then presented in Section VI. A general conclusion ends the paper in Section VII.

II. Literature Review

Studies covering ECG signals are largely listed in various states of the 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 discrete wavelet transform (DWT) such as in [7]-[9], adaptive filter in [1], [3]-[4], [10]-[14], and digital filter in [4], [15]-[19]. 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. Filtering is the

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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 related works, an addressing of the cascaded digital FIR filter is given, as presented in [4] K. K Patro et al. 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 simulation. The performance measures are related to SNR, MSE and Power Spectral Density (PSD). In [18], P.C. Bhaskar et al., by considering the best SNR resulted from different windowing techniques, cascaded FIR filters have been carried out as FIR low passHamming, FIR high pass rectangular and FIR notch rectangular combination for removing the same noises from ECG signal. The ECGsamples have been extracted from the MIT-BIH database. The authors in [20] proposed four combinations of cascaded filters for removing the undesired frequencies from the noisy ECG signal. The FIR HPF filter was designed by Blackman window, the adaptive filter was designed by NLMS algorithm, the notch filter (50Hz) and the 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 [4].

As an observation, a cascaded filter can remove different noises depending on desired frequencies, which it involves many steps such as shown in Fig. 2 Therefore, an FIR filter can be designed by different windowing methods. But there is an important remark to point which concerns the fact that the window function selection has not been covered in the above mentioned algorithms, i.e. the use of window technique should not be random due to its impact on the quality of the resulting signal. Each type of window has its own characteristics (fixed or adjustable), especially if used it in the formation of a certain combination of filters. This last idea constitutes the originality in this contribution.

The windowing technique is selected for this application for its simplicity of using, instead of the adaptive windowing technique, because there is a problem in relation to the signal filtering by using this technique, as discussed in [22], Chinmay et al., proposed an adaptive window technique designed for de-noising and smoothing the ECG signal and clarify that a problem in ECG signal de-noising task is baseline wandering noise. In this regard, a method which transformed the signal from the time domain to frequency domain and vice versa through the fast Fourier transforms to remove low frequency. This method is used as concurrently to the adaptive window technique which is used to remove high frequency noise such as PLI and EMG.

The main limitation which is faced in this method is that the removal of low frequency can additionally remove some part of the ECG signal.

III. Theoretical Background

A. Typical Cardiac Cycle

The appearance of the morphology of the ECG signal can be decomposed into different components, labelled as P, Q, R, S and T waves. Each component has its own typical appearance; a typical ECG cycle is shown in Fig. 1 [7]. PR interval represents the timing of the conduction through the atria to the ventricles. The PR segment represents the period of conduction from the AV node down the bundle of its boundary, through the bundle branches to the muscle [15]. The QRS complex illustrates the depolarization of the right and left ventricles [8]. The ST segment is due to the time between ventricular depolarization and repolarization. The QT interval represents the time of ventricular activity [23].

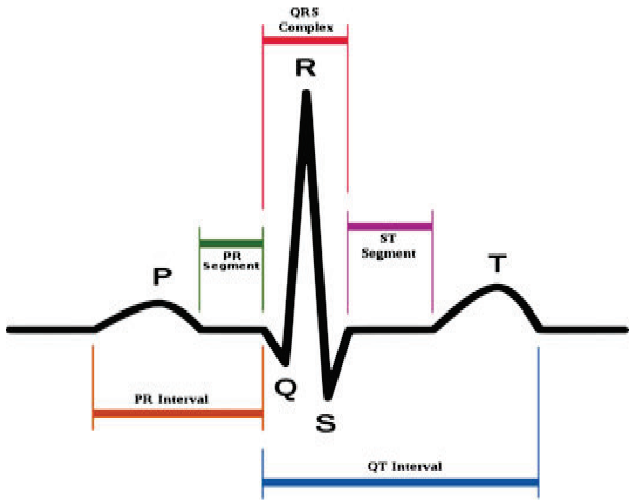

Fig. 1. Typical one ECG cycle

B. Finite Impulse Response (FIR) Filters

Finite Impulse Response (FIR) filters are the foremost basic digital signal processing system parts. 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 [16].

FIR filter has generally a linear-phase response. The impulse response of a linear-phase FIR filter has even or odd symmetry which can be used to exploit and reduce the number of multipliers [24]. 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, i.e. can be adapted according to the need and more easily than analogue filters [25].

However, there are three main methods for FIR filter design namely:

- Optimal Filter Design Method,
- The frequency sampling technique,
- The windowing method.

The FIR filter can be designed by different windowing method. There are two window kinds namely: fixed and adjustable windows.

IV. Proposed Method

There are many other methods used for designing FIR filters such as equiripple, least square, maximally flat instead the windowing method, regarding the ECG de-noising problem [15]. Many studies have been made to prepare the combination of various types of digital filters, i.e. high pass filter, band stop filter and low pass filter in order to remove the noises BLW, PLI and EMG, respectively from ECG signal.

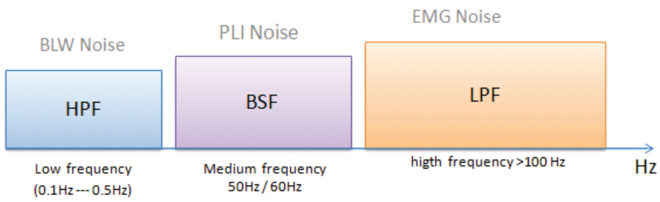

Fig. 2. Filter types corresponding to major noises' frequency

Fig. 2 shows different noises compatible with various appropriate frequency bands based on digital filter types respectively. Moreover, all the preview works have adopted the windowing method to design the cascaded FIR filter. To the best of our knowledge, there is no single study that proves or disapproves the impact of window selection on the performance of this filter. To address this issue, a new method has been proposed to prove the impact of windows selection on the cascading filters, i.e. select the windows that give the best outputs performances of SNR and MSE for each filtering stage, (HPF, BSF and LPF). Our approach divided into two stages (see Fig. 4), in the first one, the three windows of the best performance are selected among the existing ones from FDA Tools, for each type of digital FIR filter separately, by using one FIR filter alone as shown in Fig. 3 i.e. The SNR and MSE performances of this filter are tested at each time when configured it on any available window, through applying them on this filter. The comparison has been done by determining the performance of each window in each type of this filter separately. So that we can get considering for emphasis the validity of the selected windows, when applying them on the combination of three filters on cascade (HPF-BSF-LPF).

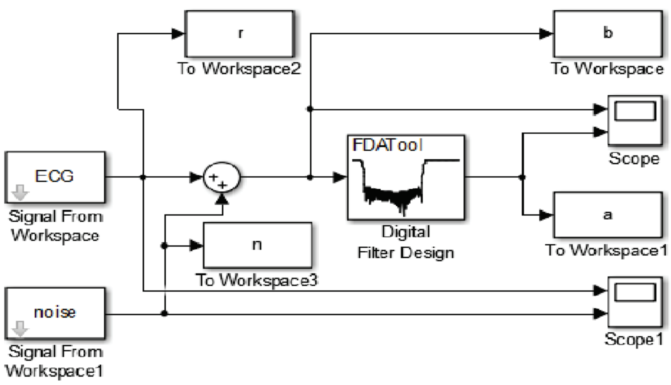

Fig. 3. Simulink FDA Tools model used in the first stage

In the second stage, the three windows produced by the first stage are used to form the cascading FIR filter. The cascaded filters they are the combination of high pass, band stop and low pass filters (HPF-BSF-LPF) respectively, thence all these filters are in a fixed order of (360) is chosen for the de-noising ECG signal task. The three windows taken from the first stage are distributed on these three cascaded filters. Hence the disposition of these windows will produce twenty seven possible configurations of cascaded filters, i.e. let's ($F^W = 27$) represent the cascade FIR filter configurations such as shown in the Table 3. Where the F is the number of filters and W is the number of windows, i.e. there are three selected windows and three filters (HPF-BSF-LPF), there will be a total of 27 cascaded FIR filter configurations. According to the condition of SNR and MSE measurements, the best configuration (BC) has been selected among all possibilities configurations, to be used for filtering the noisy ECG signals in all cases generally.

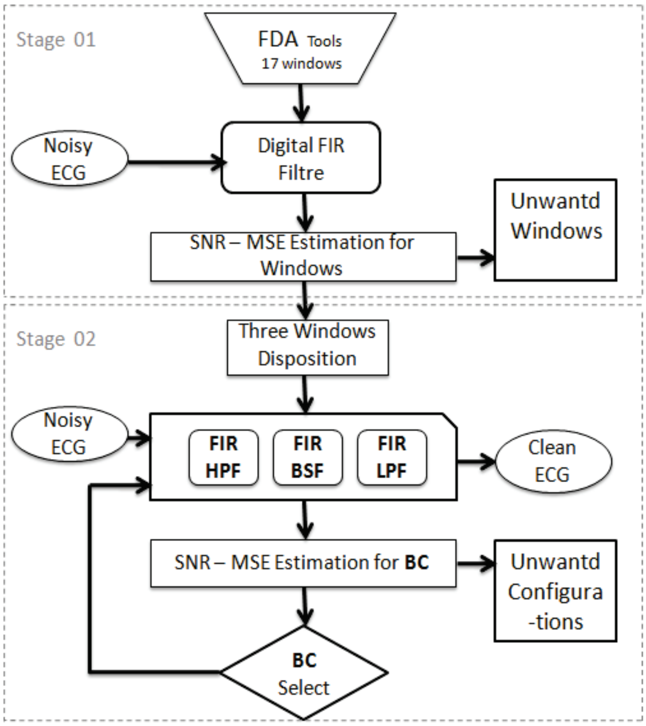

Fig. 4. Diagram of the proposed method

Fig. 4 illustrates a detailed work plan that lists the steps that have been identified to reach the desired results. As mentioned above, this proposed method is divided into two parts and may seem separate in appearance, but in fact, each portion complements the other. The following steps illustrate the algorithm procedure.

Algorithm Pre-Processing Captured ECG signal

Input: Noisy ECG signal *E* Input.
Output: ECG without noises *E* Output.

Stage 01: Select the Three Windows.
1: Load *E* Input.
2: Initialization of each filter type separately (HPF, BSF then LPF), by choosing orders, cut-off frequency and simple frequency in FDA Tools.
3: Filtering *E* Input signal by using all window methods (17 windows) available in FDA Tools.
4: Computing and comparing all 17 results according to SNR and MSE parameters for each filter, and select the desired three windows.
Stage 02: Select the Best Configuration (BC).
1: Load *E* Input.
2: Insert the three windows resulting from the first stage and distributing them on cascaded filters.
3: Filtering ECG signal by using all probable configurations (27 configurations) which are applied to cascaded FIR filter.
4: For each configuration, measure the SNR and MSE parameters and select the best configuration from the 27 possibilities configurations.
5: Using the best configuration to overcome the major noises that escort the ECG signal in all cases on general.

V. Simulation Experiment Technique

For decades, private centres in hospitals have collected and stored data from patients' health care, in order to refer to them in many cases, such as diagnosis of morbidity and post-clinical follow-up of individuals or general statistics, even more, conducting continuous scientific research to develop the field of biomedical, medicine in general, such as chronic disease detection and prevention, drug extraction and organs' surgery. Thus, the ECG database can be obtained in the hospital ECG monitoring device or it can be obtained by hand tools available in laboratories such as ECG Simulator Multi-Parameter Patient Monitoring device. But in our study of the ECG signal processing, the Physionet Database from Physiobank Library is used [26], which is freely available on-line, 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 experiment manipulation and implement using MATLAB and SIMULINK environments.

A. Evaluation on 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 meritoriously 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 and01 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.

Therefore, from the raw ECG signal, as mentioned in[26], the effects of BLW and PLI noises originally are associated with it from the Physiobank ATM (PTB diagnosis ECG database), as shown in Fig. 5(a), below. 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 just added to identifying the performance levels of proposed work, such as shown in Table 4.

B.White Gaussian Noise (WGN)and EMG Approximation

As previously mentioned, the records taken from the database in force on this proposal contain two types of noise inherent in the raw ECG signal, which are the BLW and PLI [26]. If anticipated, non-stationary in the raw ECG signal, the noises that corrupt it such as EMG and others are also of non-stationary nature [2]. Hence, this referred that EMG noise is overlapped with the ECG signal and they are of the same nature, then this noise has the same high frequency feature as WGN. Advocating, in this paper, the WGN with -27.42 dB is adopted as the muscles contraction effect source, and embedded it in the ECG signal in which distorts the information signal and lowers its quality to achieve different SNR levels [27]. This is evident in the raw signal and in the mark representing whole noise contamination, as in the Figs below.

C. SNR and MSE Parameters

ECG Signal de-noising approaches are usually estimated by the signal to noise ratio (SNR) and mean square error (MSE) parameters on dB [15]. Furthermore, these parameters have the ability to know how close the de-noised signal is to the original signal assessment.

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

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

Eqs (1) and (2) are used to calculate SNR 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 [28]. Hence the better de-noising method should have a higher SNR and a lower MSE.

D. Digital FIR Filter

A digital FIR filter of M order has the transfer function can be described by:

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

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 b_k are the filter coefficients [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, the sampling frequency of (360 Hz >= 2*(original ECG signal)) and cut-off frequency selected according to the undesired noise frequency. So, these material equipment and Simulation methods are combined to achieve our main aims and fill in the results of the experiments noted in the following tables, in the next section.

E. 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 [24], such as appearing in Table 1. In 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]. The adjustable window has been set up with one or more parameters provided as shown in the Table 2

TABLE 2
ADJUSTABLE WINDOWS PARAMETERS

Adjustable window	Provided parameters
Chebyshev	Sidelobe attenuation = 102 dB
Gaussian	Alpha _ α = 2.8
Kaiser	Beta _ β = 0.5
Taylor	Nbar = 5 Sidelobe level = -30 dB
Tukey	Alpha _ α = 0.5

VI. Results and Discussion

Within the scope of our knowledge from the proposed method experiments, it has been noticed that the process for noises disposal depends on several factors that directly affect on 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 the last one?

Then, how to determine the cut-off frequencies bands with appropriate order for each filter?

And what are the sorts of windows which are used for configuring the filter or any other technique for filtering the signals?

Moreover, how to provide the window parameters?

TABLE 1
FIRST STAGE RESULTS OF SEVERAL WINDOWS USING SNR AND MSE PARAMETERS

FDA Tools Windows	HPF		BSF		LPF	
	SNR	MSE	SNR	MSE	SNE	MSE
Barttlet	20.3240	0.0069	33.5913	0.0056	47.9247	0.0042
Bartt-Hann	19.7721	0.0070	34.5890	0.0055	47.9914	0.0042
Blackman	19.1996	0.0071	34.9675	0.0055	48.0038	0.0042
Blac-Harris	18.9564	0.0071	34.9193	0.0055	48.0041	0.0042
Bohman	19.1508	0.0071	34.8423	0.0055	47.9959	0.0042
Chebyshev	18.9991	0.0071	34.9423	0.0055	48.0035	0.0042
Flat Top	18.6690	0.0071	34.3739	0.0055	47.9689	0.0042
Gaussian	19.6787	0.0070	35.6455	0.0054	48.2133	0.0042
Hamming	19.9687	0.0070	36.1834	0.0054	48.4048	0.0041
Hanning	19.6121	0.0070	34.9235	0.0055	48.0127	0.0042
Kaiser	**26.7647**	**0.0063**	**38.8508**	**0.0051**	**54.3886**	**0.0035**
Nuttall	18.9761	0.0071	34.9283	0.0055	47.9979	0.0042
Parzen	19.0402	0.0071	34.7434	0.0055	47.9969	0.0042
Rectangular	**27.3729**	**0.0062**	**37.5115**	**0.0052**	**55.0158**	**0.0035**
Taylor	20.9328	0.0069	**39.4952**	**0.0050**	**49.2664**	**0.0040**
Triangular	20.3465	0.0069	33.6694	0.0056	47.9515	0.0042
Tukey	**21.6162**	**0.0068**	33.9052	0.0056	48.0352	0.0042

TABLE 3
THE LAST STAGE RESULTS OF DE-NOISING PERFORMANCE OF SEVERAL CONFIGURATIONS USING SNR AND MSE PARAMETERS

Configuration selecting for HPF-BSF-LPF	Performance		Observed effect
	SNR	MSE	
K-K-K	24.6386	0.0065	improved
K-K-R	24.6576	0.0065	improved
K-R-K	24.9078	0.0065	improved
K-R-R	24.9287	0.0065	improved
K-K-T	24.4231	0.0065	improved
K-T-K	22.0208	0.0068	improved
K-T-T	21.8661	0.0068	improved
K-R-T	24.6849	0.0065	improved
K-T-R	22.0343	0.0068	improved
R-R-R	25.4414	0.0064	improved
R-R-T	25.1830	0.0065	improved
R-T-R	22.3860	0.0067	improved
R-T-T	22.2100	0.0068	improved
R-R-K	25.4205	0.0064	improved
R-K-R	25.1539	0.0065	improved
R-K-K	25.1337	0.0065	improved
R-T-K	22.3718	0.0067	improved
R-K-T	24.9044	0.0065	improved
T-T-T	18.0584	0.0072	Not improved
T-T-K	18.1456	0.0072	Not improved
T-K-T	19.4965	0.0070	Not improved
T-K-K	19.6093	0.0072	Not improved
T-T-R	18.1537	0.0070	Not improved
T-R-T	19.6332	0.0070	Not improved
T-R-R	19.7582	0.0070	Not improved
T-K-R	19.6192	0.0070	Not improved
T-R-K	19.7481	0.0070	Not improved

In the first stage, the results noticed that Kaiser (K), Rectangular (R) and Taylor (T) windows are the three windows which achieved acceptable performances, by comparison between their SNR and MSE assessment in HPF, BSF then LPF separately, which were selected for the second stage experiments. As mentioned earlier, the minimum mean square error and maximum signal to noise ratio is the right condition to accessing an optimal adaptive configuration algorithm to achieve the de-noising task. Therefore, Kaiser window is achieved significant improvement in each HPF, BSF and LPF. Whereas, the Rectangular window results were very excellent values in HPF and BSF but in BSF it is proved an acceptable result if comparing it with Kaiser and Taylor windows. On the other hand, Taylor window has detected a high performance in BSF and acceptable performance in LPF if compared it with Kaiser and Rectangular windows; furthermore, in HPF it has less value than Tukey window performance but it is satisfy.

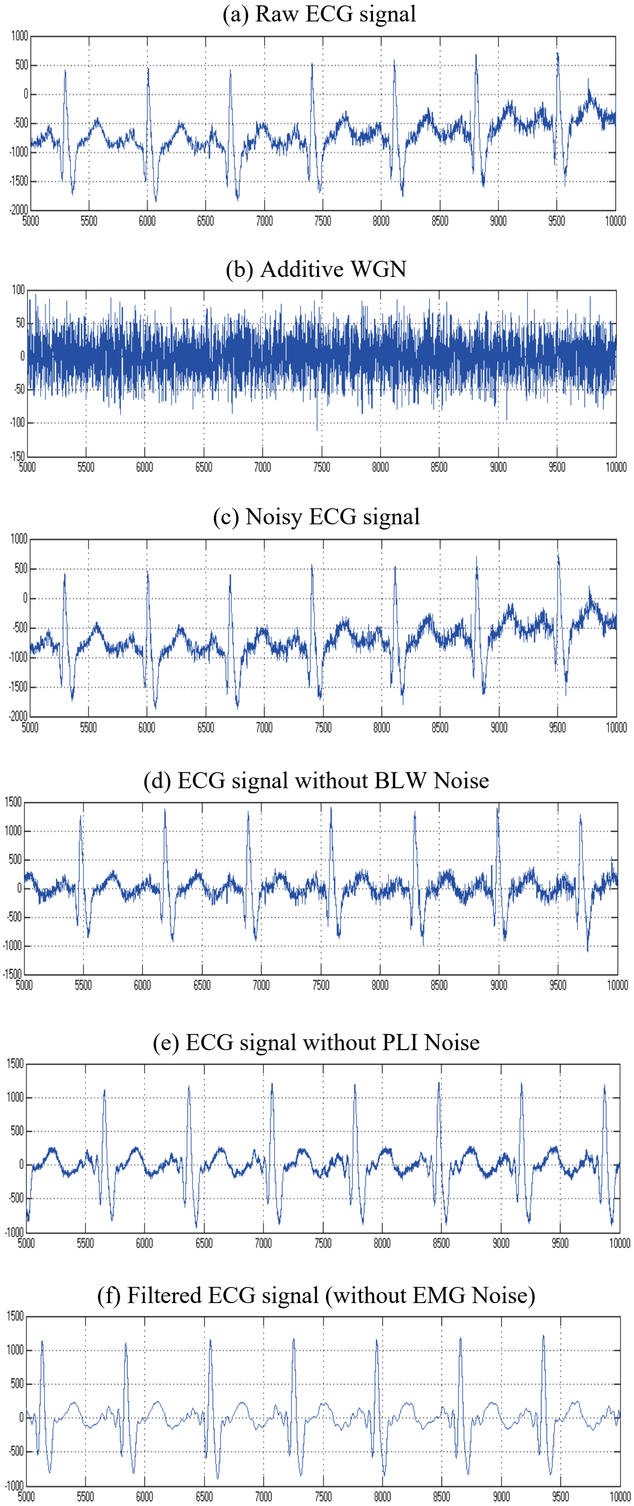

Fig. 5. Steps of de-noising ECG signal using record ID S0010_rem derived from the PTB diagnostic database

Table 3 shows the results obtained from the final phase of eliminating the predominant interferences of the ECG signal, by applying all possible experiments to the three filters used in the pattern of the serial system representing (HPF, BSF and LPF) respectively. The windows extracted from the previous stage are used in these experiments, and the outputs SNR and MSE performances are compared, which they were given by each configuration, where the best obtained results are concentrated in the first and the middle of Table 3 that derived according to the improved configurations respectively. Among these configurations, the structure (R-R-R) is the best configuration who is achieving better results according to the above mentioned rules for maximum SNR and minimum MSE.

Figure 5 shows the steps of stage 2 from the proposed method applying BC technique in which the raw ECG signal passes during noises cancelling. Furthermore, the PTB database records contain clear ECG signals grouped with respiration effect, and 50/60 Hz effect, then added to it a WGN to form a noisy ECG signal by three major noises according to the next points.

(a) Raw (original) ECG signal was recorded for Patient N^{o}. 001, this indication is accompanied by BLW and PLI noises, which have been diagnosed with the disease of Myocardial Infarction, refer to additional diagnoses of Diabetes Mellitus.

(b) WGN which corrupted the raw ECG signal and produces the errors in the information, with an SNR=-27.42 dB adjusted to achieve SNR levels.

(c) The raw signal mixed with WGN (noisy ECG signal), where it passes through three phases of filtration in tags as shown in the following signals (d, e and f).

(d) The signal resulting from the first filter HPF is free from BLW noise, where it became according to the axis line 0.

(e) The signal resulting from the second filter BSF is free of PLI noise (50/60Hz) frequency.

(f) The signal resulting from the third filter LPF is free of EMG noise (de-noised ECG signal). Hence the phase response of the (R-R-R) configuration based on FIR filter technique is linear and stable with a clean ECG signal is free. Whereas, this filter design is shapes the signal waveform and maintains the main features of the smooth ECG signal in the desired manner, for more confirmation see Figs. 6 and 7.

Table 4 shows the results obtained from the conformations of our proposed approach configuration. 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, 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.

The proposed approach, which employs the different window function and deferent FIR filters, under the condition of maximum SNR and minimum MSE, detected that the ECG signal enhancement has been achieved with significant performances in each diagnostic record class and smooth output signals. However, in the context of this manuscript, the proposed method proved that it is able to eliminate the problem of determining the appropriate window for any filter to get read the undesired frequencies from any raw signal. Therefore, the use of the window technique should not be random due to its impact on the quality of the resulting signal, because each type of window, whether it is a fixed or adjustable window, has its own characteristics, especially if used it to the implementation of the cascaded filter.

In the other hand, this is not limited to improving the quality of the ECG signal solely, but rather to apply this technique to other types of signals.

TABLE 4
CONFIRMATION EFFECTS OF DE-NOISING PERFORMANCE OF PROPOSED METHOD FOR PTB DIAGNOSTIC DATABASE FOR DIFFERENT DISEASES

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

TABLE 5
COMPARISON OF PROPOSED CASCADED FIR FILTER DESIGN WITH EXISTING WORK

Author name	Physio Bank ATM database	SNR improvement after filtering(dB)	MSE minimization (%)
Patro et al., 2015 [4]	MIT-BIH NSR DATA	4.14	21.81
	MIT-BIH ECG ID DATA	2.47	35.30
Navdeep et al., 2019 [20]	MIT-BIH Arrhythmia	7.75	-
Present work	PTB diagnostic ECG database	31.2573	26.43

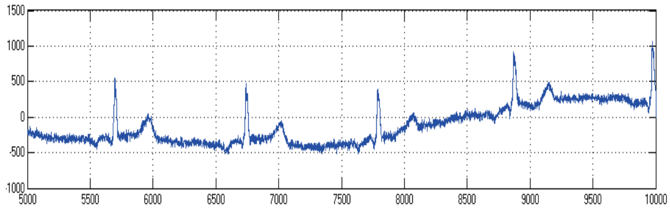

Fig. 6. Raw ECG signal before filtration

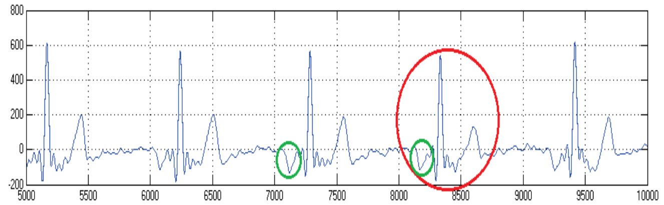

Fig. 7. ECG signal after filtration

The high performance obtained in this optimization has been compared with the existed papers, [4] and [20]. Hence, this comparison contains four types of ECG database from the Physiobank ATM. So, the significant SNR improvement and MSE minimization resulted from the deferent proposed cascade filters designs, are illustrated in Table 5.

Figures 6 and 7 represent the record ID: S0509_rem before and after filtration. The raw (original) ECG signal was recorded for Patient N°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]. Where, the resulted ECG signal was presented the real signal waveform. Hence, the red circle illustrates the morphology of one cardiac cycle; the green circles show the P wave, however, the P wave was inverted (negative) [31].

VII. Conclusion

In this paper, we have proposed an alternative method for building a cascaded FIR filter in order to enhance the ECG signal quality through two stages. In the first stage, the three desired windows are selected according to high measurements of SNR and low MSE, in which focus is mainly concentrated on configuring one FIR filter as LPF, BSF then HPF separately via different windowing techniques. In the second stage, the above selected windows are then used on the cascaded algorithm. The resulting best configuration was drawn from comparisons of the SNR’s outputs and MSE’s performances. Actually, the PTB database supplying the raw ECG signal records are contaminated by PLI and BLW noises. In addition, the WGN has been added to get the entire noisy signals. The derived best configuration proved a successful de-noising action. This approach will certainly provide an efficient additional tool in ECG signal analysis. Moreover, an extension in where an implementing of this method in specific hardware or co-simulation environments is recommended.

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