DESIGN AND IMPLEMENTATION NOVEL FILTER TO DE-NOISING THE ELECTROCARDIOGRAM SIGNALS

Fotuh Abdulkareem Ali*, Mousa Wali*, and Thanaa H. Abd
*Department of Computer Technical, Electrical Engineering Middle Technical Collage, Middle Technical University, Iraq
*Ministry of Science and Technology, Space and Telecommunication Directorate, Baghdad, Iraq
*Corresponding author: eng_fotuh@yahoo.co.uk (Fotuh A. Ali),

ABSTRACT
One of the most important vital signs that contain a large amount of information about the human health status is the electrocardiogram (ECG) signals. Numerous researches have been done to improve the sensitized signal from the heart in order to reduce the possibility of errors in diagnosing symptoms, which are determined by drawing an ECG signal Electro. The purpose of this research is to present novel system that improves and reduces the noise accompanying the ECG signal by applying a set of filters individually and collectively. The results of presented filters show robust performance against different noise types.

Keywords: Electrocardiogram (ECG) signals, Baseline Wander, Arifacts, and Finite Impulse Response (FIR) filter.

I. INTRODUCTION
The process of myocardial signal drawing has earned great interested by many researchers in recent years because it contains important information related to human health [1]. Where the process of creating an ECG, signal is done by contracting and relaxing the heart muscle, as mentioned in many previous studies. However, the description of the ECG muscle signal, contains the P wave (due to atrial depolarization), the QRS complex (due to atrial depolarization and ventricular depolarization) and the T wave (due to
ventricular depolarization) [2, 3]. Figure. 1 shows an ECG signal waveform for a healthy person as mentioned in [2, 4].

The ECG signal in general varies from patient to patient, depending on the type of disease. Therefore, the subject of drawing the ECG signal is very important for diagnosing diseases [5]. Whereas, this signal is accompanied by a lot of noise, which is often documented on the ECG signal. Therefore, we have to raise this noise without affecting the ECG signal. In general, the noise accompanying the ECG signal is divided into two main groups, as follows: the first group includes contraction of the muscles of the body, the baseline drift, ECG amplitude adjustment due to breathing, artefacts resulting from changes in the skin's electrode resistance with electrode movement [6].

The second group consists of power line interference, electrical contact noise, instrument noise generated by electronic devices, radio frequency, and electrical
To remove the combination noise of the ECG signal two types of Digital filters can be implemented. Which are either software applications or hardware applications. However, the hardware can be implemented by utilizing DSP processor. On the other hand, the software applications can be implemented by programming high level software using digital signal processing language such as MATLAB program [8]. Some parameter should be taken in account for real time applications such as heart rate should be in the range of 72 beats/minute as well as the filter must be performed once every 0.83 seconds for each beat.

The structure of this paper is organized as follows. Section describe ECG noise types and III and Section V describes the database and methodology that have been utilized to extract the results respectively. While the results presented in section IV, Finally, the conclusion is given in Section V.

II. ECG Noise Types

The ECG signals normally suffered from different noise types such as baseline wandering, muscle artifacts, and power line interference. The presence of types of noise with the ECG signal negatively affected in obtaining a correct and accurate ECG signal. Figure. 2. Shows a sample of ECG signal.
The ECG signal prone to be affected by the association noise, due to it is inherently characteristics such as low frequency and low amplitude signal. Therefore, the ECG signal must be separated from the accompanying noise. The ECG signal noise can be categorized according to the following:

1. Baseline Wander

The low frequency noise that is affected the ECG signal in the range of 0.3-0.5 Hz, denoted as baseline wander or baseline drift noise. The baseline wander would be increase with increase the impedance of the electrode, as well resulting of physical exercise, muscle fatigue or breathing during the recording of the ECG signal. However, to remove the baseline of the ECG signal a high pass filter with a cut-off frequency of 0.5 Hz can be utilized [9, 10]. Figure 1 shows the ECG signal corrupted with present of the baseline wander [11].

![ECG signal corrupted by baseline wander](image)

In fact, to remove the baseline wander from the ECG signal, a Finite Impulse Response (FIR) filter named Hannon filter to remove the low frequencies. So, to remove the low frequencies, the desired frequency response $H_d(\omega)$, and unit sample response $h_d(n)$, can be determine as [12]:

$$H_d(\omega) = \sum h_d(\omega)e^{-j\omega n}, \quad (1)$$

Where the values of $H_d(\omega)$ in the range:
\[ H_d(\omega) = \begin{cases} 
0, & 0 < |\omega| < \omega_c \\
1, & \omega_c < |\omega| < \pi 
\end{cases} \] (2)

While, the unit sample response \( h_d(n) \), represent as:

\[ h_d(n) = \int H_d(\omega) e^{-j\omega n} d\omega. \] (3)

The unit sample response \( h_d(n) \), can take the values according to the following function:

\[ h_d(n) = \begin{cases} 
1, & |n| = 0, 1, 2, ..., L \\
0, & otherwise 
\end{cases} \] (4)

The impulse response of the FIR can be denoted as:

\[ h(n) = h_d(n) \times w(n) \] (5)

where, the filter window determined as \( w(n) \), and represented for the Hannon window as:

\[ w(n) = \frac{1}{2} \left[ 1 - \cos\left(\frac{2n\pi}{N-1}\right) \right] \] (6)

Where, number of samples in the range of \( 0 \leq n \leq N-1 \).

2. Powerline Interference:

One of the most types noise that effected on the recording of the ECG signal is the power line interference (PLI). The PLI oscillates between the frequencies 50/60 Hz. The PLI generally caused by the following [13]:

- Produced due to electromagnetic interference with the power lines.
- Devices that place on the patient generate electromagnetic field (EMF).
  The equipment components carried harmonics and frequencies.
- Unsuitable ground of ECG devices.
- The alternating current fields due to the loops of the device’s cables.
- Various electric devices in the examination room caused of inducing 50 Hz in the input circuits of the ECG device.
To reduce the effect of the PLI, we implement second order FIR filter with the transfer function:

\[ H(z) = (1 - z_1 z^{-1})(1 - z_2 z^{-1}), \]

\[ H(z) = 1 - 2 \cos(w_0) z^{-1} + z^{-2} \quad (7) \]

The FIR have been used in this paper, has a large bandwidth, which enables it to reduce noise near the central frequency \( w_0 \) of 50 Hz. Thus, it has the possibility to reduce the effect of noises near the central frequency of the utilize filter.

3. Electromyogram Noise (EMG)

The presence of noise accompanying the ECG affects a significant and clear effect on the ECG signal layout, especially during exercise. As a result, the forms of low-amplitude waves are very little or completely obscured. The main problem of trying to get rid of EMG noise is that the main frequency of this noise is related to the frequency of 50/60 Hz, as this noise cannot be removed by narrowband filtering since the activity of the heart muscle is within this frequency band. However, due to the inherent property of the ECG signal the signal itself is frequent and a special technique can be implemented to reduce such this noise like the processing of evoked potentials. Therefore, depending on the nature of the successive beats of the heart muscle and the presence of interference noise, the successful noise limit can be taken through the mean of the group limited to a specific QRS morphology. Figure.4 shows an ECG signal interfered by an EMG noise.
So, to reduce the EMG noise within the ECG signal, we will consider a filter with n-point moving average (MA) filter. Where, the MA filter general equation can be represent as:

\[ y_n = \sum_{k=0}^{n} b_k x(n - k) \]  

(8)

The input and output filter represent by \( x \) and \( y \) respectively. While the filter coefficient denoted by \( b_k \). The filter order represented by the sample \( N \), as well the filter weight named \( k \), within the value of 0, 1, 2, 3, ..., \( N \).

4. Electrode Motion Artifacts

The Motion artifacts noise considered as serious phenomenon that is affect the ECG signal measurement. Motion artifacts noise are associated with cardiac movement resulting from cardiac or pulmonary movement and can cause disturbance in signal recording. In another words the Motion artifacts produced by skin stretching which is increase the skin impedance around the electrodes. However, the Motion artifacts can be detected in the frequency range of 1 to 10 Hz. to 10 Hz in the electrocardiogram. Figure.5 shows an ECG affected by electrode motion artifacts [2].
In this paper, we adopted adaptive filter to cancelation the motion artifacts as in [15]. In general, the adaptive filter required two input signals \((d(t) \text{ and } u(t))\) named primary and the reference signal respectively. As well, the widely adaptive filtering algorithms are used are the Least Mean Square (LMS) and the Recursive Least Square (RLS) [16]. The adaptive noise canceller schematic diagram shown in the Figure.6.

Figure 5: ECG affected by electrode motion artifacts [14]
III. DATABASE

In this paper, the database of MIT-BIH arrhythmia [17, 18], is considered to evaluate the performance of the proposed ECG signal denoising method as input signal. The MIT-BIH arrhythmia collected from the ATM database viewer, with a digitalized frequency of 360 Hz (samples/Hz/second/channel).

IV. THE METHODOLOGY

In order to clean the ECG signal from an excessive amount of noise that is deform the ECG signal shape. In this paper, we program a method to eliminate the noise of the ECG signal. However, in this paper, a Matlab code designed as different filter as well as combined together as Cascade filter to eliminate the noise. The filters included as Finite Impulse Response (FIR) filter, which is procedure with window functions method to eliminate the low frequencies. The derivative filter applied to reduce the artifacts noise. To reject the high frequencies, we applied Notch filter to cut off the 60 Hz frequencies. These filters were applied individually and collectively to study their effect on noise reduction in an ECG signal. These filters were applied according to the following steps

1. Appling Hanning Window (as low pass filter) to eliminate the EMG noise. As well as, determine the frequency response (magnitude and
phase), pole-zero plot, and the Fourier spectra of the recording input and output EMG signals.

2. In the second stage we applying derivative-based filter. The derivative-based filter considered to remove the of low-frequency of the artefacts noise, so that the gain at the maximum frequency present in the input signal is unity. As in the first step, the we obtaining the frequency response (magnitude and phase), pole-zero plot, and the Fourier spectra of the input and output signals.

3. In the third step, we applying the notch filter to eliminate the power line interference noise in the range of 60 Hz. However, we obtain the ECG signal frequency response (magnitude and phase), pole-zero plot, and Fourier spectra of the input and output ECG signals.

4. In the fourth step, we Apply all three filters equations on the ECG signal in series, and determine the combined filter effects. Finally, we get the ECG signal frequency response (magnitude and phase), pole-zero plot, as well as the Fourier spectra of the input and output ECG signals.

V. Results

The performance analysis of applied filters on the ECG signal considered in the time domain, where the results of these techniques are more attractive and expressive for eye than others. However, the techniques have been utilized to eliminate the baseline noise in the range of 0.1 Hz to 0.6 Hz a high pass filter (Hanning filter) is utilized to do so. In the Figure. 8, an ECG signal in term of Time (Sec) verse the Voltage (mV) is shown. Where, both of unfiltered and filtered ECG signal shown in Figure. 7 (a and b) respectively.
Fig. 7: ECG signal in term of Time (Sec) verse the Voltage (mV). (a) Unfiltered ECG signal and (b) Filtered ECG signal with Hanning filter.

The ECG signal with two cycle represent in Figure. 9. We can observe the activity of the filter on reduction the high frequencies as shown in Figure. 8 (b) with respect to original signal as shown in Figure. 8 (a).
Fig. 8: Two cycle of ECG signal in term of Time (Sec) verse the Voltage (mV).
(a) Unfiltered ECG signal and (b) Filtered ECG signal with Hanning filter.

The power spectrum density for both filtered and unfiltered signal shown in the Figure 9. Figure 9 (b) shown the successful effect of the Hanning filter to remove the low frequencies as was present for the same ECG signal as presented in Figure 9 (a).
Fig. 9: The PSD of ECG signal in term of Frequency (Hz) verse the Magnitude (dB). (a) Unfiltered ECG signal and (b) Filtered ECG signal with Hanning filter.

In Figure. 10, the Magnitude and Phase response of ECG signal filtered by Hanning filter is presented. Figure. 10 (a) shows the filter magnitude performance analysis. We can observe that the filter magnitude does not exceed 0 dB with less than 0 degree.
Fig. 10: The Magnitude and Phase response of ECG signal filtered by Hanning filter. (a) Viruses of Magnitude (dB) with respect to the Frequency (Hz) and (b) Viruses of Phase (degrees) with respect to the Frequency (Hz).

After the signal has been filtered by the low pass filter it is will be filtered by the derivative filter, Where the filtered ECG signal shown in the Figure. 11 (a and b). The derivative filter show it is superior performance to eliminate the XXXX noise. We can observe the filtering process behaviour on the two cyclic ECG signal as represent in Figure 12. (a and b).
Fig. 11: ECG signal in term of Time (Sec) verse the Voltage (mV). (a) Unfiltered ECG signal and (b) Filtered ECG signal with Derivative filter.
Fig. 12: Two cycle of ECG signal in term of Time (Sec) verse the Voltage (mV). (a) Unfiltered ECG signal and (b) Filtered ECG signal with Derivative filter.

While in term of PSD, the ECG signal filtered by the derivative filter, shown in Figure. 13 (a and b) in term of Frequency (Hz) verse the Magnitude (dB). Figure. 13 (a) shows the unfiltered ECG signal as well Figure. 13 (b) shows Filtered ECG signal with Derivative filter.
Fig. 13: The PSD of ECG signal in term of Frequency (Hz) verse the Magnitude (dB). (a) Unfiltered ECG signal and (b) Filtered ECG signal with Derivative filter.

Figure 14 (a), shows the magnitude versus the frequency of the derivative filter, as it shown the frequency of the derivative filter is less than 2 Hz which is suitable value to eliminate the artefact noise that is present in the ECG signal.
As noted above, the ECG signal is exposed to noise, which is likely to be at high frequencies that are within 60 Hz. Therefore, the use of a notch filter contributes to reducing this noise, and therefore it can be cancelled permanently. The displayed Figure.15 represents the ECG signal of the notch filter before and after using this filter as shown in Figure.15 (a and b). Where,
Figure.16, represents of a sample of ECG signal of two cycles of the filter before and after the filtration process. In this way, the visible effect of the filter is shown by reducing and eliminating the high frequencies that are within the 60 Hz.

Fig. 15: ECG signal in term of Time (Sec) verse the Voltage (mV). (a) Unfiltered ECG signal and (b) Filtered ECG signal with Notch filter.
Fig. 16: Two cycle of ECG signal in term of Time (Sec) verse the Voltage (mV). (a) Unfiltered ECG signal and (b) Filtered ECG signal with Notch filter.

The notch filter response in the term of PSD shown in the Figure. 17 (a and b). it is can be clearly observed that the PSD signal is eliminate within the 60 Hz.
Fig. 17: The PSD of ECG signal in term of Frequency (Hz) verse the Magnitude (dB). (a) Unfiltered ECG signal and (b) Filtered ECG signal with Notch filter.

The Magnitude and Phase response of ECG signal filtered by Notch filter, shown in the Figure. 18. Where the viruses of Magnitude (dB) with respect to the Frequency (Hz) shown in Figure. 18 (a). The cut-off frequency range of the notch filter is clarified. The viruses of Phase (degree) with respect to the Frequency (Hz) shown in Figure. 18 (b).
Fig. 18: The Magnitude and Phase response of ECG signal filtered by Notch filter. (a) The viruses of Magnitude (dB) with respect to the Frequency (Hz) and 
(b) The viruses of Phase (degree) with respect to the Frequency (Hz).

However, to accomplish the main idea of this article. All of the above-mentioned filters are all collected and applied directly to the ECG signal as cascade filter. The result of the cascade filter represented in the Figures.19-21 respectively. We can observe that the cascade filter has higher effect to eliminate various noise type. Figure. 19 represent the elimination of the noise in term of Time (Sec) verse the Voltage (mV) for both filtered and unfiltered ECG signal.
Fig. 19: ECG signal in term of Time (Sec) verse the Voltage (mV). (a) Unfiltered ECG signal and (b) Filtered ECG signal with Cascade filter.

Figure. 20 (a and b), shows the PSD of ECG signal in term of Frequency (Hz) verse the Magnitude. The cascade filter eliminate the frequencies above the 50 Hz, which is supressed the 50 Hz noise.
Fig. 20: The PSD of ECG signal in term of Frequency (Hz) verse the Magnitude (dB). (a) Unfiltered ECG signal and (b) Filtered ECG signal with Cascade filter. While, the Magnitude and Phase response of ECG signal filtered by Cascade filter shown in Figure. 21. The viruses of Magnitude (dB) with respect to the Frequency (Hz) shown in Figure. 21 (a). As well, Figure. 21 (b), shows the viruses of Phase (degree) with respect to the Frequency (Hz).
VI. Conclusion

In this paper, different ECG signal filters types have been utilized individually and combined to suppress the ECG signal noises. Where we found that the effect of the individual filter has less effect to suppress the noise in compared to the cascade filter. However, with implementing the cascade filter, it is showing
the ability to eliminate of different noise directly without the need to eliminate the noise individually which is need more process time and less effective. The proposed cascade filter shows it is ability to noise elimination which is enabled it to be the best choice for ECG signal noise elimination processing.

VII. References

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