Noise Removal from ECG Signal Based on Filtering Techniques

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***Abstract*— The Electrocardiogram (EKG or ECG) is a semi-cyclic, rhythmically, and synchronous signal with a cardiac function through the passive sensory apparatus in which the apparatus is performing as generator of bioelectric signal mimicking the function of the heart. The EKG signals are inherently weak, and noisy signals built of many variable components due to many environmental factors in which it may include but is not limited to changes in body temperature, body movement, and line frequency 50/60 Hz. The ECG signal cannot be conditioned, amplified, nor reproduced directly and therefore, digital filtering techniques with adjustable window are used in this paper. The paper analyses several models of Finite Impulse Response (FIR) filters of low-pass and high-pass and their aspects in term of response time, gain, and harmonic distortion, and rejection to determine the best band-pass filtering model to reproduce an ECG signal that closely resembles the actual Heart function of a patient. A hybrid filtering model is proposed and experimentally tested. Mean square error (MSE) is used to estimate a signal goodness. MATLAB environment has been used for the experimental part to simulate the signals. This research work has been considered in the context of a larger project that consists of a complex wearable health monitoring system comprising biosensors, wireless communication modules and links, control and processing units, medical shields, wearable materials and advanced algorithms used for decision making and data extracting. The proposed filtering technique is useful in the medical data preprocessing phase.**

***Keywords*— ECG signal, filtering techniques, MSE, noise removal, Savitzky-Golay filter.**

I. Introduction

Electrocardiogram EKG signals are an electrical representation of the heart function by a transducer component/device, which senses and converts the mechanical energy (vibration) into electrical signal for filtration, processing, and further analysis by specialists to assess the health condition of a Patient.

The conversion is achieved by the movement to a diaphragm that is placed on the skin of the patient as part of a balanced bridge configuration in which the instrument shall record voltage disturbances as a result of the diaphragm senses the vibration of the Heart.

Fundamentally, there are two kinds of noises associated with an EKG signal: one regards a high-frequency component called electromyogram noise, Power-Line interference noise (50-60) Hz, and the other one being the Additive White Gaussian noise AWGN. AWGN is a noise that is associated with any random signal or process that occurs in nature. Other noises with low-frequency are the baseline wandering and the motion artifact. These noises in the ECG signal may lead to misinterpretation [1]. Fig. 1 shows the ECG waveform that explains the clinical characteristics of the ECG, comprising wave interval, timings and wave amplitudes. The ECG signal is distinguished via five valleys and the peaks marked up as P, Q, R, S, T respectively, and scarcely there is a U wave in the signal, almost absent, having a very low amplitude. The ECG waveform embodies the atrial depolarization which is the period needed for an electrical impulse formed from the sinoatrial node to multiply over the atrial musculature and with the duration around 0.06-0.11 seconds [2].

The paper has the following structure. Section 2 analysis some relevant research works in this field. The noise types in ECG signal are discussed in Section 3. Some basic concepts regarding the used filter techniques used in the proposed hybrid approach are underlined in Section 4. Important features of Savitzky-Golay filter, relevant for ECG filtering are underlined also here. Section 5 presents the experimental environment and the data set. Section 6 offers the implementation details of the proposed hybrid filtering method and finally, the conclusions are emphasized.

This research work has been considered in the context of a larger project that consists of a complex wearable health monitoring system comprising biosensors, wireless communication modules and links, control and processing units, medical shields, wearable materials and advanced algorithms used for decision making and data extracting. The proposed filtering technique is useful in the medical data preprocessing phase.

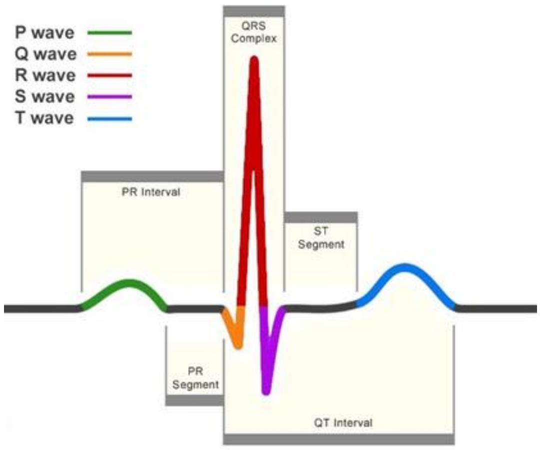

Fig. 1 ECG Waveform [21]

II. Related Works

Several denoising techniques were proposed and applied in the former researches to reduce the interferences from the actual ECG signals. Singh et al. [5] designed FIR filter using many windows techniques such as Blackman, Hanning, Rectangular, Hamming, and Kaiser windows, to remove a Baseline wander from an ECG signal. The Signal-to-Noise Ratio (SNR) of these techniques was calculated as per the spectral densities and average power. The techniques based on the Rectangular and Kaiser windows give better results but, due to the high number of the filters order, the computational load is very complex. As for Blackman and Hanning windows, the filter's order was extremely high. In this research, the Kaiser window has proved to be as a better choice among the others. Priyanka and Kaur, G. [6] used different windowing techniques: Kaiser, Rectangle, Hamming, Hanning and welch windows to denoise the power line interference, muscle and EMG noises from ECG signals. AlMahamdy M. and Riley H. B. [7] presented and applied many methods to denoise and at several noise levels from 5-45 dB SNR. The analysis and comparison shown that the performs of NeighBlock wavelet method was the best among the others.

P.C.Bhaskara and M.D.Uplaneb [8] presented a low pass FIR filter using several windowing techniques to cancel high-frequency Electrocardiogram (EMG) interference utilizing Distributed Arithmetic (DA) based on FPGA and Xilinx system generator software. Kaiser Window gave an excellent performs to remove the noise. Choudhary M. and Narwaria R. P. [9] dealt with the signal to noise ratio and average power to make comparison among three digital filters (Infinite-impulse-response (IIR)) which are Butterworth, Chebyshev Type-I, and Type-II. The results have shown that using low-pass Butterworth filter could remove more noise than the others. Mahawar et al. [10] have used a windowing method, Kaiser and Dolph –Chebyshev (DC) to develop FIR lowpass filter with use of high attenuation. The results can be inferred quantitatively and visual inspection based on signal error measures such as Percentage Root Mean Square Difference (PRD), Percentage root mean square difference1 (PRD1), SNR, and MSE. Sharma M. and Dalal H. [11] used FIR and IIR digital filters utilizing windowing techniques in order to cancel the low-frequency baseline wander from the abnormal EKG signal. Rastogi, N. and Mehra, R. [12] developed an integrated technique, which consolidates Daubechies wavelet decomposition with many thresholding methods with the IIR digital Chebyshev or Butterworth filter to denoise the Baseline Wander interferences. DWT shows a good capability to decompose the signal and wavelet thresholding was great to remove the noise from a decomposed signal. The quantitative evaluation results of both filters were based on MSE, peak signal to noise ratio (PSNR) and signal to interference ratio (SIR). The final results show that the denoising performance of both Butterworth and Chebyshev methods gave almost the same efficiency.

Patial P. and Singh K. [4] dealt with FIR Low Pass Filter using various window techniques i.e. Kaiser, Hamming, and Hanning to filter an EKG signal and remove any interferences from it.

Sreedevi G. and Anuradha B. [13] analyzed and compared between IIR and FIR filters and their performances according to the Power Spectral Density (PSD) to denoise the Baseline wander from noisy EKG signal. Mbachu C.B. and Offor K.J. [14] used a FIR digital notch filter with Hamming window for powerline noise (50Hz) removal in the ECG signal. The performance efficiency of the Hamming algorithm compared with an adaptive filter. The result has shown that the adaptive filter was the best to process the ECG signal.

In this context, this approach analyses several models of Finite Impulse Response (FIR) filters of low-pass and high-pass and their aspects in terms of response time, gain, harmonic distortion and rejection to determine the best band-pass filtering model to reproduce an ECG signal that closely resembles the actual Heart function of a patient. A hybrid filtering model is proposed and experimentally tested.

III. Noise Types in the EKG Signal

The EKG signal noise is an undesirable signal intervenes with the wanted signal. These artifact signals can arise from several external and internal sources. Using noise reduction is a significant stage to solve most of the issues in the analysis of biomedical signal due to the difficulty of extracting useful information from the ECG signal. The main noise sources are [3]: baseline wandering, EMG noise (Muscle noise), motion artifacts, power line interference, electrode contact noise, channel noise, and high-frequency noises in ECG.

IV. ECG Filtering Techniques

The techniques of filtering are essentially utilized for signal preprocessing and have been widely executed in the ECG analysis systems. Nature of ECG signal is quite sensitive, even a small noise if mixed with an original signal that will make changes in the signal characteristics. Therefore, the data that is corrupted by noise must either be filtered or disposed of.

Table I presents three types of noise which are contained in our ECG signal, with the reference to the corresponding frequency range of it and its sources.

TABLE I. NOISE TYPES WITH ITS CHARACTERISTICS

Type of Noise	Noise Sources	Frequency Range
Baseline wander	Respiration and body movement.	Below 1 Hz (0.15-0.5) Hz
Electromyogram (EMG) Noise	Generated by electrical activity of the muscle.	>100 Hz
Motion Artifacts	Occurs due to the stretched of skin, which leads to a change in skin voltage at the second layer of the skin (stratum lucidum).	0.4-15 Hz

The most important windows functions that will be used in this paper are Chebyshev, Tukey, Taylor, and Kaiser.

A. Chebyshev Window

This filter is utilized to process the signal for its good characteristics. The main-lobe of it has a minimum width for the given side-lobe attenuation. Chebyshev window is equiripple where the height of side-lobe is similar at all frequencies.

B. Taylor Window

This window is similar to the Chebyshev window, but with Chebyshev window, the main-lobe is narrowest for a specified side-lobe level. Using Taylor window lets you make trade-offs between a width of main-lobe and side-lobe level. The distribution of Taylor eschews boundary cutoff; therefore, Taylor window side-lobes monotonically reducing. Further, the coefficients of this windowing method are not normalized.

C. *Tukey Window*

It is a significant window due to its effective characteristics and it is also called tapered cosine window.

D. *Kaiser Window*

Altering a parameter α allows the side-lobe level of this window to be controlled with regard to the main lobe peak. The parameter β of Kaiser Window affects the side-lobe attenuation α db [5]. The adjustment of the filter length allows modifying the main-lobe width.

The examination of the four filters have suggested that the Chebyshev filter algorithm offers the best result for Low-pass filter from frequencies between 0.05 Hz through 100 Hz respectively. The below four filters were examined under the same parameters values 100 cut-off frequency (Fc), 400 Hz order filter, and 360 Hz sampling frequency (Fs). The tests results revealed that the magnitude response were as follow:

- Low-pass Chebyshev window has shown sharp roll-off at 97 Hz (-3 dB) with a clean signal starting at 103 Hz. Ringing in the sampling signal has accord at frequencies greater than 105 Hz with low power of less than -100 dB in which the data set becomes very insignificant to cause any issue with the calculation.

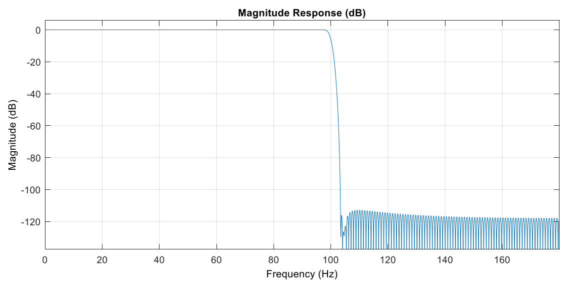

Fig. 2 Chebyshev window Magnitude Response -Lowpass

- Low-pass Kaiser window has shown minor ripple effects with sharp roll-off at 98 Hz (-3 dB), and sharp ringing starting at 100 Hz (-22 dB). Hence, the data set could impose significant interference to the ECG signal.

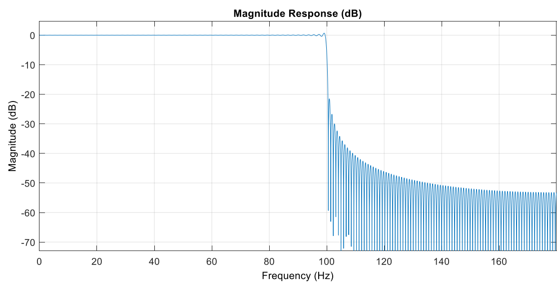

Fig. 3 Kaiser window Magnitude Response -Lowpass

- Low-pass Taylor window has shown ripple effects with sharp roll-off at 99 Hz (1 dB), and sharp ringing starting at 101 Hz (-23 dB). Hence, the data set could impose significant interference to the ECG signal. Note: The Side-lobe level was set to 13.

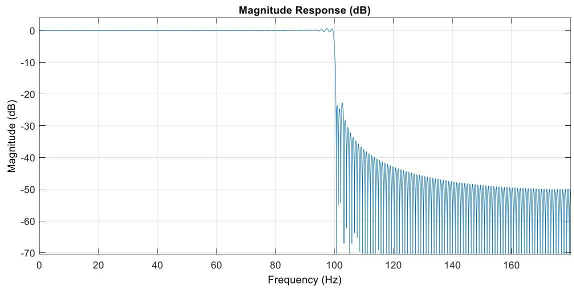

Fig. 4 Taylor window Magnitude Response -Lowpass

- Low-pass window has shown low ripple effects with sharp roll-off at 98 Hz (1 dB), and sharp ringing starting at 101 Hz (-22 dB). Hence, the data set could impose significant interference to the ECG signal.

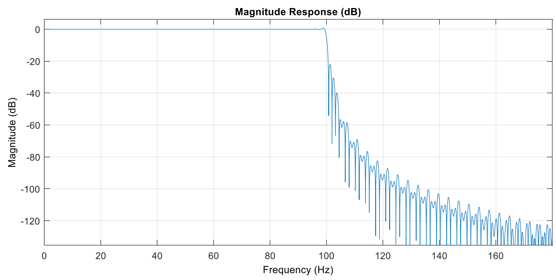

Fig. 5 Tukey window Magnitude Response -Lowpass

The Savitzky-Golay (SG) filters can be applied in smoothing noisy ECG signals. Peak and shape conserving property of the SG filters has proved to be quite efficient for precise ECG processing. Birle el al. [19] used Savitzky-Golay filter to remove noise and smooth the noisy EKG signal without losing much information, characteristics, and originality of the signal. Nahiyan, K. M. T., and Abdullah-Al Amin [20] proposed a method based on Savitzky-Golay filter and moving average filter to cancel the baseline wander from an EKG signal, these combination filters allow approximating the baseline wander very efficiently. Although in some cases it distorts the signal of EKG to some extent, comparing it with other polynomial fitting methods shows its superiority in accuracy and simplicity. In this proposed new approach, we applied the Savitzky-Golay filter for the stage related to removing the baseline wander and motion artifact and smoothing the EKG signal.

V. ENVIORMENT AND DATASET

Filter design and analysis tools have been used in this paper to design FIR low-pass and high-pass filters using window design methods [15], [16]. WFDB toolbox was utilized in MATLAB to converts the ECG signal dataset

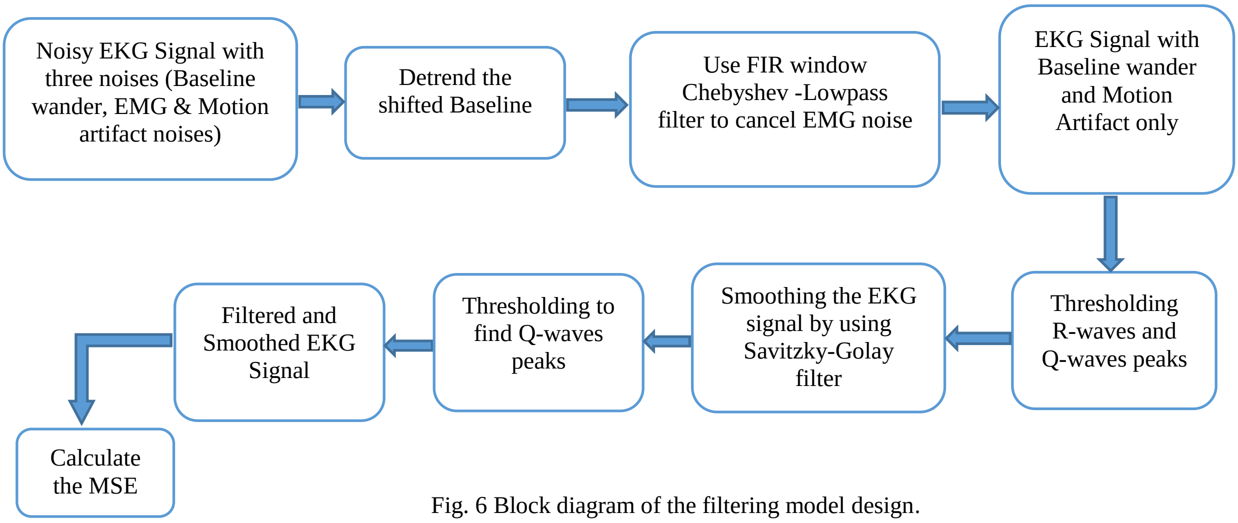

Fig. 6 Block diagram of the filtering model design.

files into (.mat) files so that they can be performed in MATLAB.

The ECG database used in this study was obtained online from PhysioNet website [17] that offers free permission access to huge collections of recorded physiologic signals. The dataset called MIT-BIH Arrhythmia Database contains recorded signals digitized at 360 samples per second per channel with 11-bit resolution over a 10mV range [18]. The annotated ECG signals are described by a text header file (.hea), a binary file (.dat) and a binary annotated file (.atr), while the noise recordings were created using physically active volunteers and standard ECG recorders, electrodes, and leads.

VI. Implementation and Results

The ECG signal dataset used in this research is corrupted by three types of noise during the recording process. Also, the baseline of signal has different trends which do not represent the true amplitude. In this work, we presented a new technique by integrating windowing methods, thresholding algorithm, Savitzky-Golay filtering in order to denoise the signal as shown in Fig. 6.

The process of implementation of the proposed technique was accomplished through several steps illustrated below:

Phase 1: Firstly, we converted the used ECG dataset by using WFDB tool to the formula (.mat) and then load it and display it in MATLAP, as shown in Fig 7.

Phase 2: The baseline shift appears on the signal which effects the real amplitude of the signal badly. Fundamentally, we need to detrend the signal by fitting a low-order polynomial to the signal and utilized the polynomial to detrend it, the entire signal detrended perfectly as shown in Fig. 8.

Phase 3: After that, we applied the FIR windowing method using the Chebyshev lowpass filter to denoise the EMG noise which is greater than 100Hz. We used a sampling frequency 360 Hz for the filter because the recording dataset were digitized at 360 samples per second. The cut-off frequency was 100Hz. The used filter order was 400. We utilized higher order to get more accurate result during our testing period and we found out that if the filter order increased over 400 this causes the raise of a ripple determining new noise. We can also decrease the filter order but this will be at the expense of accuracy. Memory size and processor speed of the device should be taken into consideration to determine the number of filter order. The high frequency noise has been removed with less than 5mV as shown in Fig. 9.

Phase 4: It regards thresholding the peaks of QRS-complex by using thresholding algorithm. In this phase, we threshold only the R-wave and the S-wave. R-waves were detected by thresholding the peaks above the voltage 0.5mV by using the function MinPeakHeigh. The R-waves are separated by more than 200 samples. Therefore, we utilized a function MinPeakDistance to specify the peaks' distances and then we could cancel the unwanted peaks. In the case of S-wave thresholding we inverted the filtered signal and then we applied the same function and values of R-wave. Fig. 10 shows the thresholding peaks in the signal.

Phase 5: Following, we attempted and determined the Q-waves locations. Locating the Q-waves by thresholding the peaks results in detection of undesirable peaks where the Q-waves and the noise are overlapping with each other. Consequently, firstly we have filtered the signal and then found its peaks. Savitzky-Golay filter is applied to eliminate the baseline wander and motion artifacts noise in the signal. Changing the values of filter's order and frame effects the accuracy of filtering results.

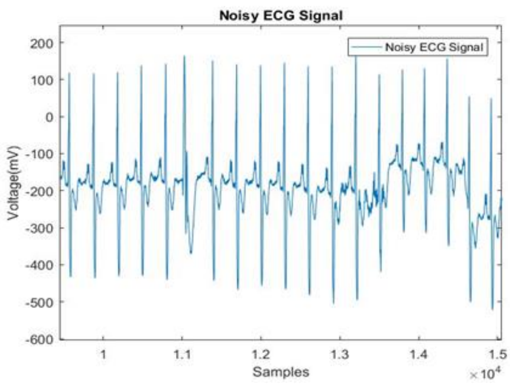

Fig. 7 Segment of noisy ECG signal.

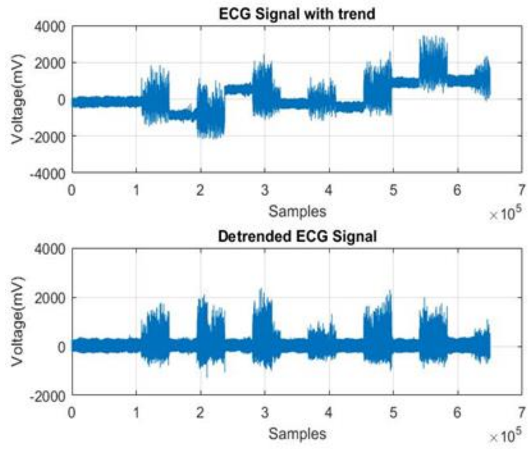

Fig. 8 48-hour recording ECG signal with trend and after detrend.

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order and the value 9 of the frame parameter give better results. Fig. 11 and Fig. 12 show the ECG signal after smoothing the signal.

Phase 6: We executed a peak detection on the smoothed signal and then utilized logical indexing in order to detect the Q-waves locations between -0.2mV and 0.2mV. The Q-waves are separated by more than 30 samples. Below Fig. 13 shows the detected QRS-complex in the filtered ECG signal.

Phase 7: Apply the Mean Square Error (MSE) algorithm to calculate the average difference among the QRS-complex of the raw, detrended, filtered, and smoothed signal. As shown in Table II.

TABLE II. MSE OF QRS-COMPLEX

Signal	**Mean Square Error (MSE)**		
QRS-complex	***R-wave***	***S-wave***	***Q-wave***
Original vs Detrended	53.8323	52.9964	54.7763
Original vs Filtered	567.1675	-272.1602	10.9185
Original vs Smoothed	567.1676	-272.1602	10.9185
Detrended vs Filtered	513.3352	-325.1566	-43.8577
Detrended vs Smoothed	513.3352	-325.1566	-43.8577
Filtered vs Smoothed	1.6899e-05	-2.9398e-06	-3.1697e-06

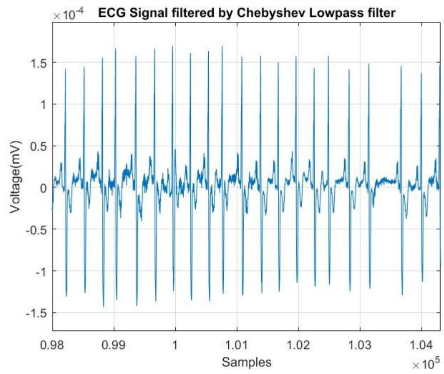

Fig. 9 ECG Signal filtered by Chebyshev Lowpass filter.

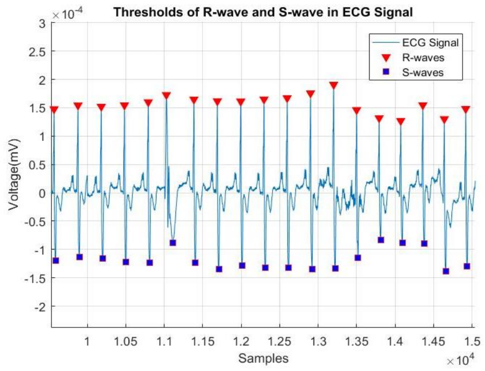

Fig. 10 Thresholds of R & S-waves in ECG

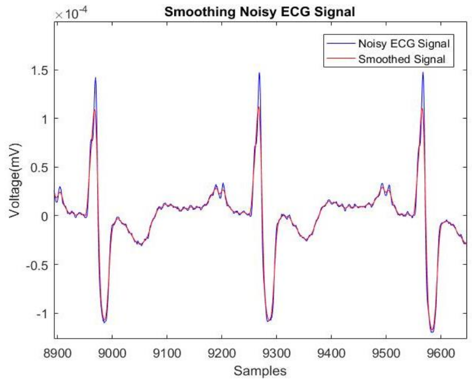

Fig. 11 Smoothing in ECG Signal.

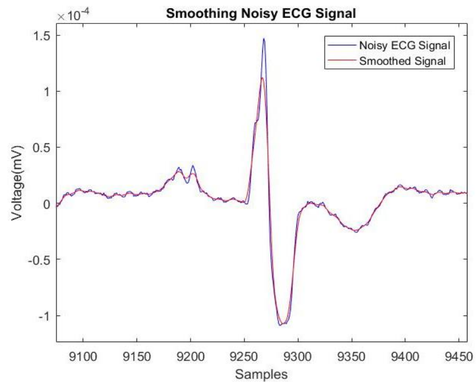

Fig. 12 Enlarged the Smoothed ECG

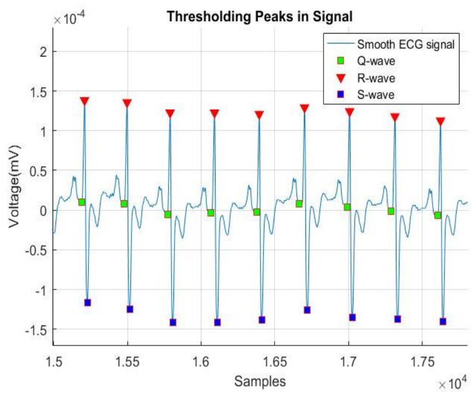

Fig. 13 Threshold QRS-complex in filtered

VII. CONCLUSION

In this work different windowing techniques has been studied and analyses according to their magnitude responses, the examination of filters responses have suggested that the FIR Chebyshev filter algorithm offer the best result for Low-pass filter from frequencies between 0.05 Hz through 100 Hz respectively, and it could remove the electromyogram (EMG) noise perfectly. The dataset of ECG signal used in this research contains a baseline shift which does not represent the real amplitude of the signal. Therefore, we must detrend the signal before to apply any filtration on the signal, we fitted a low order polynomial to the signal and used the polynomial to detrend it. Thresholding the peaks of QRS-complex is very important where it corresponds to the depolarization of the right and left ventricles of the human heart. It is necessary in the feature extraction stage; therefore, it can be utilized to define a patient's cardiac rate or predict abnormalities in heart function. Locating the Q-waves by thresholding the peaks results in detection of undesirable peaks where the Q-waves and the noise are overlapping with each other, so smoothing the signal first is required thence find the peaks. Savitzky-Golay filter is applied to eliminate the baseline wander and motion artifacts noise in the signal. Filtering the ECG signal using SG filter was efficient although in some cases it reduced the R-waves voltage to a certain extent.

The future step in our research will focus on analyzing appropriate techniques for feature extraction in order to keep only relevant information from each acquired ECG.

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