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Measurement of Electrocardiographic Signals for Analysis of HeartConditions and Problems

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ABSTRACT:*People who suffer from heart or heart-related diseases mostly experience heart attacks if these diseases are not detected early enough and treated. This underscores the need for a very reliable means of detecting these diseases to save the patients from these attacks which are increasing in proportion all over the world. Electrocardiography (ECG) is the electrical activity of the heart and it generates a biomedical signal referred to as ECG signal or simply ECG, and the appearance of this signal conveys much clinical information regarding the conditions and problems of a patient. Therefore proper interpretation of this signal is very vital in the diagnosis of heart problems. ECG signal amplitude is very small, about 1.0 mV and the signal is naturally contaminated by other biomedical and non-biomedical signals. The biomedical signals are electroencephalogram, electromyogram and baseline wander, while the non-biomedical signal is power line interference. These contaminating signals must be removed from the ECG signal during measurement otherwise it will convey incorrect clinical information concerning the patient's heart conditions and problems. Digital filters are employed in removing these contaminating signals and a good quality digital filter is able to remove these contaminants and still preserve the integrity of the signal. In this paper ECG signal acquisition technique, processing and interpretation are presented. Three different filters are considered: low pass andhigh pass filters and adaptive noise canceller. Matlab software tool is used to observe and record results.*

KEYWORDS:*ECG, leads, frequency spectrum, filter*

I. INTRODUCTION

Electrocardiography (ECG) is the electrical activity of the heart, and this activity generates a biomedical signal known as electrocardiographic (ECG) signal or simply ECG. The morphology of this ECG signal conveys much clinical information regarding the heart conditions and problems of a patient. Measurement of ECG signal starts with signal acquisition and this can berealised by placing electrodes directly on the arms, legs and chest [1]. ECG signal is naturally contaminated by other biomedicalsignals which include electroencephalogram(EEG) which is due to the electrical activity of the brain,electromyogram (EMG) which is due to the electrical activity of the muscles, and baseline wander which is due to respiration. It is also contaminated by a non-biomedical signal, 50/60Hz powerline interference, which is due to power supply source to the ECG measuring system. The frequency range of ECG signal is from 0.5Hz to 100Hz, baseline wanders around 1Hz frequency while EEG is above 100Hz. The EMG signal frequency can be below or overlaps with ECG signal frequency depending on body muscle movement. These signals which constitutenoise to the ECG signal must be removed during ECG measurement otherwiseit will convey incorrect clinical information regarding the patient's cardiac conditions and problems. Digital filters are used to remove these noise signals. A typical noise- free ECGis shown in fig. 1 and comprises three waves and one complex. The waves are P, T and U waves and the complex is QRS complex [2,3]. Interpretation of the signal is done by considering the shapes of the signal, the waves and complex and also the period or frequency of the signal and time intervals of the waves and complex. Different researchers have worked on ECG signal acquisition, processing and interpretation. Abdul *et al* [1] worked on the 12-lead and 3-lead ECG data acquisition systems. The authors processed the ECG signal with analogue high pass, low pass and 50Hz notch filters with analogue instrumentation amplifier amplifying the analogue ECG signal before application to the analogue filters. In [4] Ajayanalysed the 12 lead ECG signal acquisition system and processed the acquired signal exactly as done by Abdul*et al* in [1]. In [5]Anatolie*et al* carried out ECG signal acquisition and processing in their dynamic analysis of heart rate variability parameters. They used a dual channel amplifier module and a portable data acquisition module that communicates with a computer throughUSB port. Philip*et al* in [6] developed an algorithm forassessment of quality of ECGs acquired via mobile telephones and used the algorithm to assess and evaluate 1,500 12-lead ECG signals acquired on mobile telephones. In reducing powerlineinterference in ECG signal, notch, Wiener and adaptive filters can be used [7]. Comparison of the performance of the three different filters by the authors showsthat the adaptive filter removes 50Hz power interference better than the other two. Geeta and Bhaskar [8] carried out a performance evaluation of finite impulse response(FIR) filters designed with different windows in the reduction of 50Hz powerline interference in ECG signal. In [9]Mikheld and Khaled developed wavelet transform thresholding algorithm for ECG signaldenoising. The authors used four different ECG signals to study the effect of threshold value of descrete wavelet transform coefficients. These signals are considered as original and noise-free ECG signals with different morphologies.

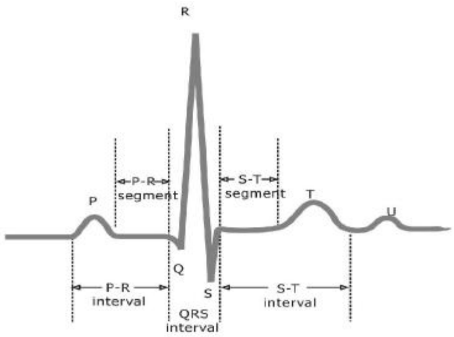

Fig. 1: Typical ECG signal

Source [2]

II. ECG SIGNAL ACQUISITION

Depolarisation of the cardiac cells is the central electrical event of the heart. This occurs when the cardiac cells, which are electrically polarized, lose their internal negativity [9].Depolarisation is distributed from cell to cell, producing a wave of depolarization that can be transmitted across the entire heart and takes place during every heartbeat.This wave represents a flow of electricity and it can be captured ordetected by electrodes placed on the skin of the body at designated sites or locations. Once depolarization is complete, the cardiac cells are able to restore their resting polarity through a process called repolarisation. This flow of electricity can also be captured by the same recording electrodes.The leadin the context of an ECG refers to the voltage difference between two of the electrodes placed on the skin and it is this difference that is recorded by ECG recording equipment known as electrocardiograph (ECG). There are 3-lead, 5-lead, 6-lead and 12-lead ECGmeasurement systems. Fig. 2 shows a 3-lead ECG system, consisting of the acquisition stage, processing stage and the display unit. The acquisition stage consists of 3 electrodes representing lead I, lead II and lead III, and an analogue instrumentation amplifier(IA).Lead I is the voltage between left arm (LA) and right arm (RA), that is LA – RA. Lead II is the voltage between left leg (LL) and right arm (RA),that is LL – RA. Lead III is the voltagebetween left leg (LL) and left arm (LA), that is LL – LA or Lead II – Lead I. This Lead III voltage is derived from Lead II and Lead I. A raw ECG signal has very low amplitude of about 1mV and therefore for effective filtration the low amplitude raw ECG signal is amplified first by the analogue instrumentation amplifier (IA). At the output of the instrumentation amplifier, acquisition is complete and the acquired signal is ready for processing and display.

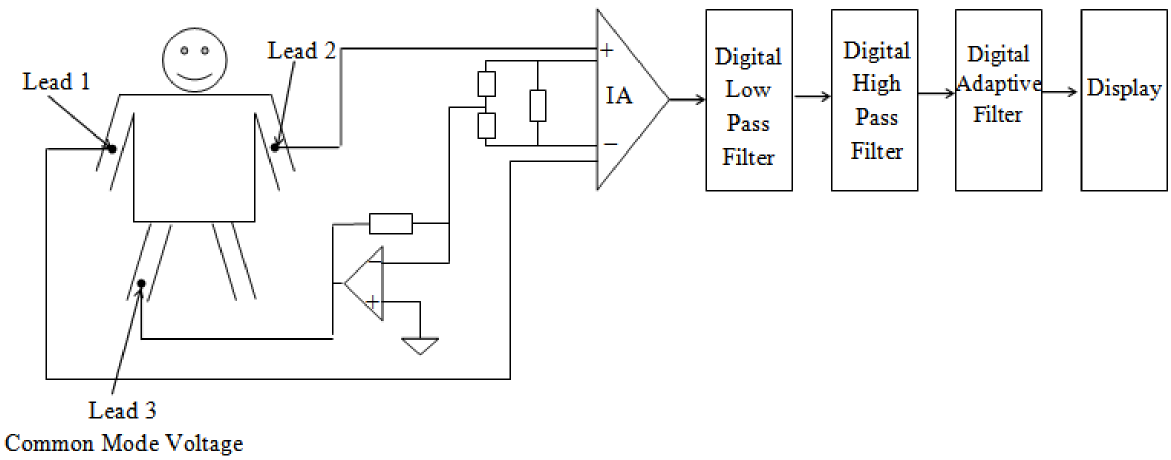

Fig.2: 3-Lead ECG Measurement System

ECG Right Leg Driver : The essence of the ECG right leg driver is to remove common mode noise generated from the body [11]. The two signals entering the instrumentation amplifier are summed, inverted and amplified in the right leg driver being fed back to an electrode attached to the right leg. The other electrodes pick up this signal to cancel the noise.

III. ECG SIGNAL PROCESSING

After acquisition of an ECG signal the signal is still contaminated by artifacts like baseline wander, encephalographic (EEG) signal and powerline interference. The patient should be still and quiet during acquisition so that the electromyographic artifact is reduced to the barest minimum. Filters are used to remove other artifacts. Matlab is used for the design.

Design of Low Pass Filter :A Finite Impulse Response (FIR) digital low filter is designed using Kaiser Window [12]. This filter removes the EEG noise and any other frequency above the upper cut off frequency of 100Hz used here. The sampling frequency is 1000Hz while the order of the filter is 100. The resulting magnitude response is shown in figures 3.

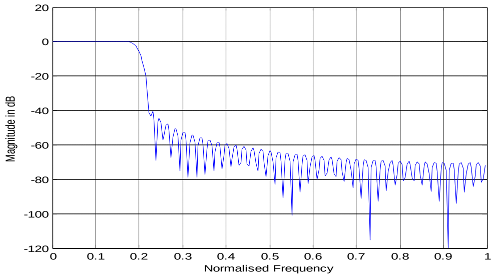

Fig 3 Magnitude response of the low pass filter

Design of High Pass Filter : An FIR digital high pass filter is designed with Kaiser Window.This filter removes the baseline wander noise and any other noise below the lower cut- off frequency of 0.5Hz used here. The sampling frequency is 1000Hz while the order of the filter is 100. The magnitude response of the filter is depicted in figures 4.

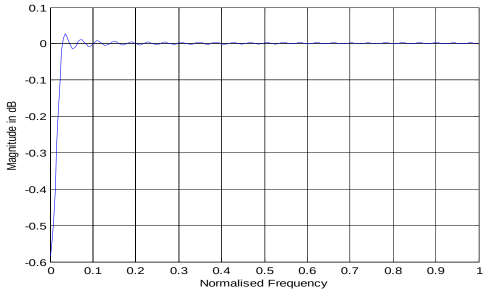

Fig 4: Magnitude response of the high pass filter

Design of Adaptive Filter : An FIR digital adaptive noise canceller is designed with a step size of 0.0010 and order of 100 to remove the 50Hz powerline noise in the ECG. The sampling frequency is 1000Hz. This filter is particularly useful in a situation where the power supply frequency to the ECG measurement system is not stable, because the adaptive noise canceller tracks the powerline interference frequency as it changes. The magnitude response is in fig 5.

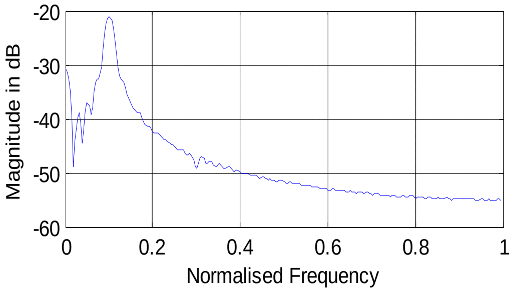

Fig. 5 Magnitude response of the adaptive filter

IV. RESULTS

In this section the various designed digital filters in section 3 are used to filter a noisy ECG signal and the effect of each filter is recorded. There are four groups in the presentation of the results; the results of the low pass, high pass, and adaptive filters, and a cascade of the three filters. An ECG signal of 3.5mV amplitude corrupt with baseline wander, EEG and 50Hz powerline noise of 0.1mV each is shown in fig 6 while the frequency spectrum or periodogram is depicted in fig 7.

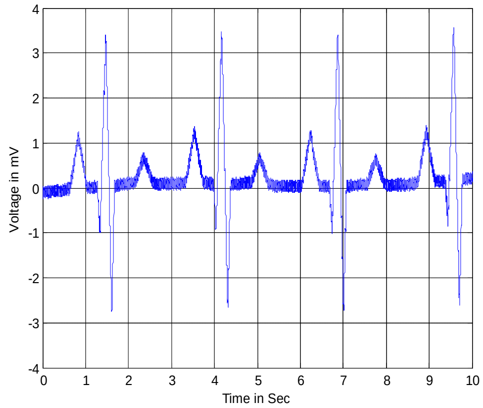

Fig 6: Corrupt ECG signal

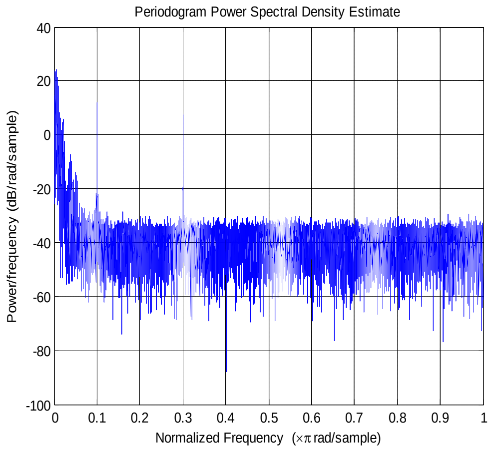

Fig 7: Frequency spectrum of the corrupt ECG signal

Filtration with Low Pass Filter : The noisy ECG signal of fig 6 is passed through the low pass filter and the output is depicted in fig 8 while the frequency spectrum of the output appears as in fig 9. From fig 7 the average power of the raw ECG signal above 100Hz is about -26.25dB whereas from fig 9 the average power of the filtered ECG signal above 100Hz (0.2 in the figure) is about-50.25 dB, implying that the filter has filtered off high frequency noise from the ECG signal.

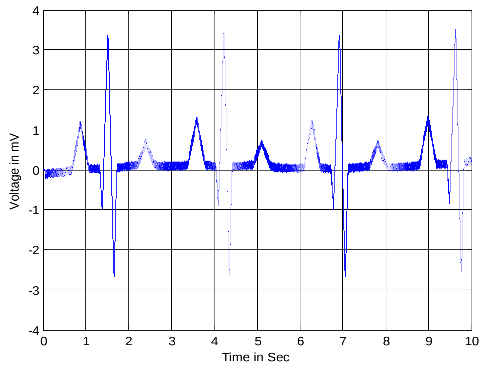

Fig 8: ECG signal after low pas filter filtering

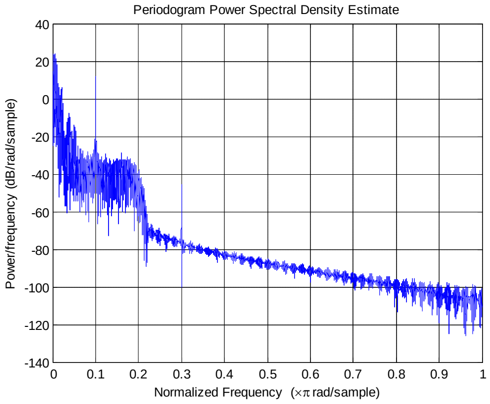

Fig 9: Frequency spectrum of ECG after low pass filtering

Filtration with High Pass Filter : The noisy ECG signal of fig. 6 is filtered with the high pass filter and the output is recorded as fig. 10 while the frequency spectrum of the output is as in fig. 11. From fig. 7, the average power of the raw ECG signal below the frequency of 0.5Hz is approximately 23.75dB, whereas from fig 11 the average power of the filtered ECG signal at a frequency below 0.5Hz (0.001 in the figure) drops to 21.5dB and the implication is that the high pass filter has reduced the baseline wander and other low frequency noise from the ECG signal.

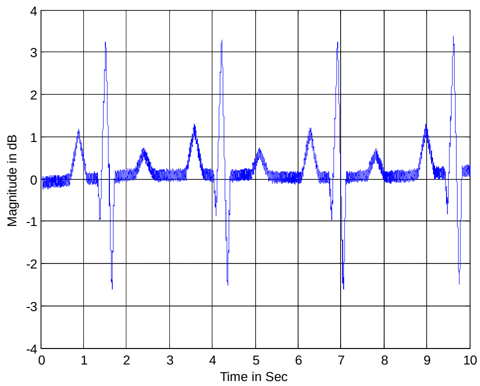

Fig 10: ECG Signal after high pass filtering

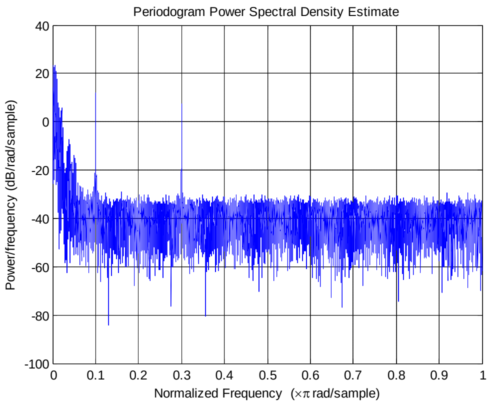

Fig. 11: Frequency spectrum of ECG after high pass filtering

Filtration with the Adaptive Filter : The noisy or raw ECG signal is applied to the input of the adaptive noise canceller. The filtered output is shown in fig. 12 while the frequency spectrum is shown in fig 13. From fig. 7 the power of the raw ECG signal at 50Hz is 10dB but from fig. 13 the power of the filtered ECG signal at 50Hz is lowered to -37.5dB which is a confirmation that the adaptive noise canceller has removed the 50Hz powerline interference from the ECG signal.

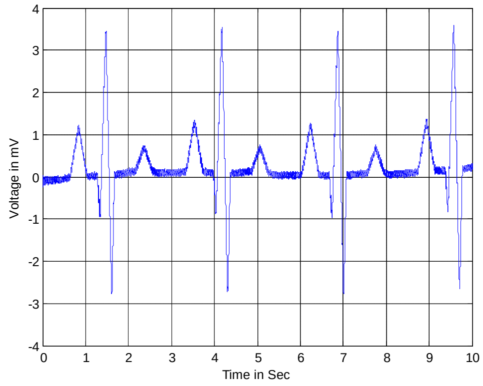

Fig. 12: ECG signal after adaptive filtering

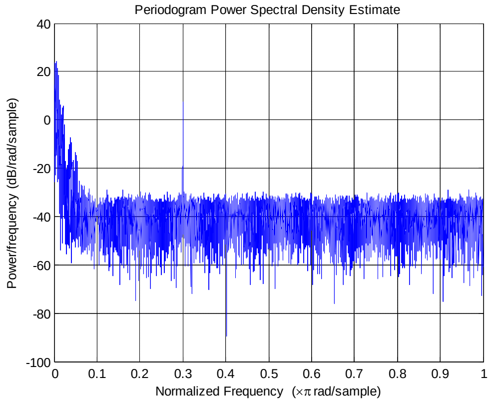

Fig. 13: Frequency spectrum of ECG after adaptive filtering

Filtration with a Cascade of Low Pass, High Pass and Adaptive Filters : The raw ECG signal of fig. 7 is applied to the input of the cascade and the output is depicted in fig. 14. Comparing fig 6 and fig. 14 it can be clearly seen that the cascade has drastically reduced the avalanche of noises in the raw ECG signal.

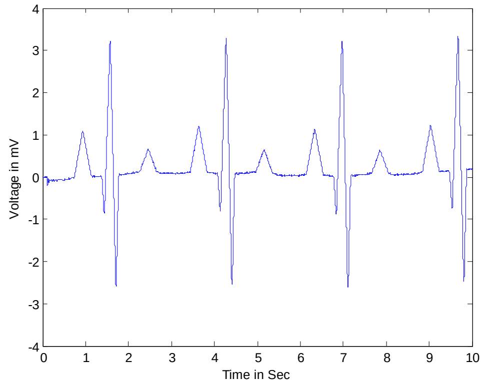

Fig. 14: ECG after cascade filtering

V. INTERPRETATION OF ECG

ECG signal conveys clinical information concerning the heart conditions of a patient. Any abnormality in the heart may change the normal morphology or frequency of the signal or both. The type and degree of change is a measure of the nature and degree of the health condition. Activation of atrial myocardium of the heart produces the P wave [3] as shown in fig. 1. During Sinus rhythm the initial part of the P wave represents the right atrial activation and the terminal part of the P wave represents activation of the left atrium by the sinus impulse with some overlap in the middle. The QRS complex as shown in fig 1 arises from the depolarization of the ventricular muscle of the heart. After depolarization of heart cells, repolarisation begins. The T wave arises from the repolarisation of the ventricular muscle of the heart. The U wave that sometimes follows the T wave is a second order effect of an uncertain origin and is of little diagnostic significance.Each heart beat produces one cycle of ECG signal. Therefore the frequency of ECG signal, that is the number of cycles produced by a patient's heart per second , which can be translated to the number cycles or beats per minute (bpm) by multiplying number of cycles per second by 60 can be used to determine whether the heart beat rate of a patient is normal or not. Normally, human heart beat rate is between about 60bpm to 150bpm depending on age [13]. Heart arrhythmias include Tachycardia which is when the heart rate is above 150bpm, andBracardia which iswhen the heart rate is below 60bpm. Other heart abnormalities include but not limited to left ventricular hypertrophy which manifests in the ECG signal as inverted T wave and old myocardial infarction which manifests in the ECG signal in form of prolonged Q.

VI. DISCUSSION

The magnitude responses of the three digital filters designed show that the filters are stable because there is no sustained oscillation in each one. The results of the filtrations show that each filter drastically reduced the noise specifically meant for it to filter. For example the noise levels of the raw ECG signal at frequency of 0.5Hz, 100Hz and 50Hz lowered at those respective frequencies when the signal was applied to the filters. The output of the cascade of the three filters produced a clean ECG signal without distortion which confirms the compatibility of the filters to one another and the optima of the orders of the filters.

VII. CONCLUSION

Accurate measurements of ECG signals are very vital in the diagnoses of heart and heart-related diseases because the rate and morphology of ECG signals convey much clinical information regarding the heart. It has been established that digital filters are indispensable in ECG measurement because they remove the inherent noises that impair reliable interpretation of the signals. Reasonable acquisition of ECG signals starts with electrodes as transducers and therefore good quality electrodes are recommended.

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