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Power Line Interference Cancellation for ECG

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***Abstract*—Power line interference corruption is a major problem in Electrocardiogram (ECG) recordings. For further processing such as QRS-complex detection and HRV analysis, cancellation of the power line noise plays a vital role in the pre-processing of ECG signal. To remove this interference, a digital notch filter was implemented. The filter was tested with MIT-BIH arrhythmia database. The power line interference 50/60 Hz (depending on the country) is modelled and added to the ECG recordings of database. The digital notch filter using pole-zero placement method was applied to the ECG signal corrupted by power line interference. Modelling and Signal Analysis were done with MATLAB®.**

***Keywords*—Power liner interference, Electrocardiogram, Notch Filter, Digital Signal Processing, Modelling and Analysis**

I. Introduction

Electrocardiogram (ECG) is the recording of the heart activity which is measured by placing the electrodes on the surface of the body with the specific biomedical amplifier. There are mainly three types of noise which can contaminate on the ECG signal. They are baseline wander noise, Electromyography (EMG) interference and 50 or 60 Hz power line interference. Among them power line interference is a significant source of noise. Data cables carrying ECG signal from the patients to display devices is influenced by Electromagnetic interference (EMI) from the 50/60 Hz power line noise. This noise degrades the signal quality and affects the tiny features which can be critical for clinical diagnosis and monitoring.

The notch filer is also called band-stop or band-reject filter since it rejects a band of frequency. However Notch filters eliminate noise at the specific frequencies. There are many methods to design Notch filters and to remove power line interference. The Pole-Zero Placement method was implemented in this paper.

II. Materials and Method

A. Database

MIT-BIH Arrhythmia Database consists of 48-half-hour ECG recordings and contains approximately 109,000 manually annotated signal labels. The recordings were digitized at 360 Hz (samples per second per channel) with 11-bit resolution over 10 mV (±5 mV) range. ECG recordings are two channels. In most records, the upper signal is a modified limb lead II (MLII), obtained by placing the electrodes on the chest. The lower signal is usually a modified lead V1 (occasionally V2 or V5, and in one instance V4); as for the upper signal, the electrodes are also placed on the chest. This configuration is routinely used by the BIH Arrhythmia Laboratory. Normal QRS complexes are usually prominent in the upper signal. Therefore, only the first channel was used for the test of power line interference suppression with notch filter. In records 102 and 104, it was not possible to use modified lead II because of surgical dressings on the patients; modified lead V5 was used for the upper signal in these records [1].

B. Power Line Interference Modeling

Electrocardiogram (ECG) signal is usually in the range of small voltage in magnitude (10μV (fetal) and 5 mV (adult)) and has frequency components from about 0.05-100 Hz. The basic shape of ECG waveform is shown in Fig. (1) [2].

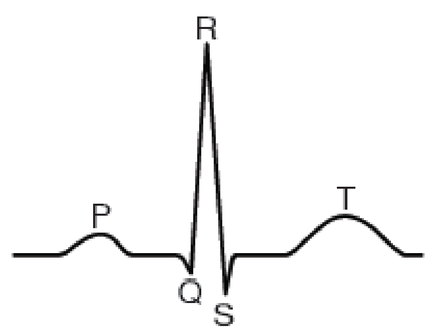

Fig. 1 Basic shape of ECG waveform

The different types of wave represent the sequence of depolarization and repolarization of the ventricles and atria.

Power line interference is modeled as sinusoids. Characteristics of model include the amplitude and frequency content of the signal. The amplitude can vary up to 50 percent of the peak to peak of ECG signal. The model in this paper is:

$$N(t) = 1\text{mV} * \cos(2 * \text{pi} * f_l * t) \quad (1)$$

where f_l is the frequency of power line interference

C. Notch Filter Design Using Pole-Zero Placement Method

Digital Notch Filter is mostly the first choice for rejecting the specific frequency of the signal. The filter is implemented using pole-zero placement method. The pole-zero placement method is an alternative approach to calculating the coefficients of infinite impulse response (IIR) filters [3]. The transfer function of IIR filter is as follows:

$$H(z)=\frac{a_0+a_1z^{-1}+a_2z^{-2}+\ldots+a_Nz^{-N}}{1+b_1z^{-1}+b_2z^{-2}+\ldots+b_Mz^{-M}}=\frac{\sum_{k=0}^{N}a_kz^{-k}}{1+\sum_{k=1}^{M}b_kz^{-k}} \quad (2)$$

where a_k and b_k are the coefficients of the filter. However in MATLAB, the function ***filter (b,a,x)*** uses the symbol b_k for numerator and a_k denominator in a reverse manner.

A digital notch filter is designed with the following specifications:

Notch frequency 50 Hz and 60 Hz
3 dB width of notch ±5 Hz
Sampling frequency 360 Hz

The radius, r, of pole is determined by the approximate relationship between r, for r>9, and desired bandwidth (bw) $r \simeq 1-[\frac{bw}{Fs} \times \pi]$. Therefore, the radius is 0.91273 for the desired filter. The transfer function for 50 Hz notch filter is

$$H(z)=\frac{1-1.2856z^{-1}+z^{-2}}{1-1.1733z^{-1}+0.8330z^{-2}} \quad (3)$$

The transfer function for the 60 Hz notch filter is

$$H(z)=\frac{1-z^{-1}+z^{-2}}{1-0.9127z^{-1}+0.8330z^{-2}} \quad (4)$$

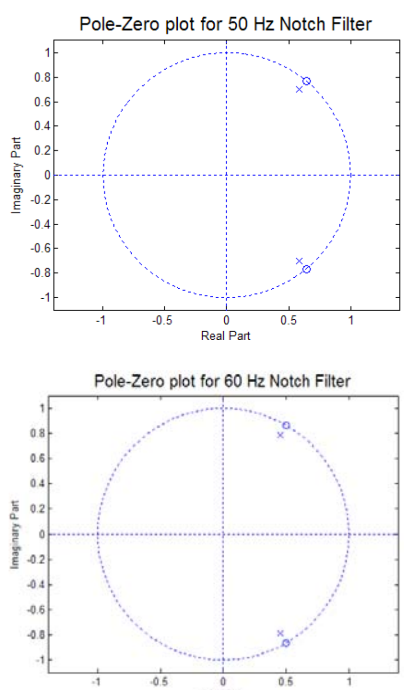

Fig. 2 Pole-zero plots for 50 Hz and 60 Hz notch filter

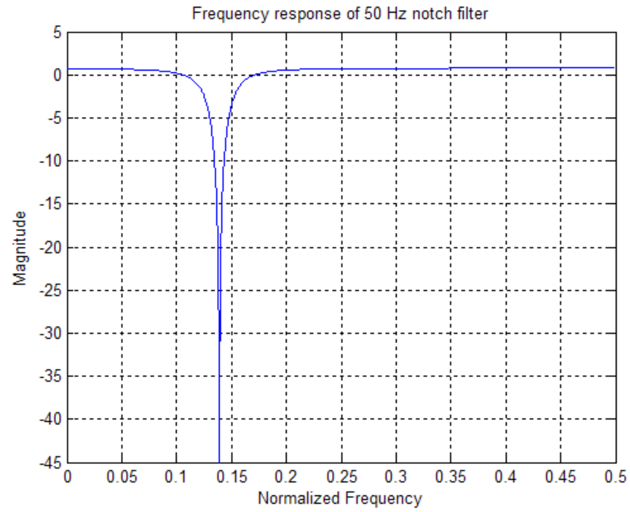

Fig. 3 Frequency response of 50 Hz notch filter

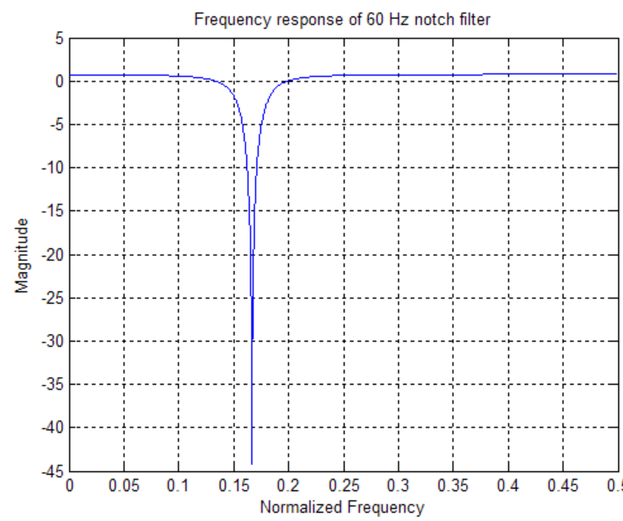

Fig. 4 Frequency response of 60 Hz notch filter

The pole-zero plots for 50 Hz and 60 Hz notch filters are shown in Fig. (2). Also, the frequency response of each filter is shown in Fig. (3) and Fig. (4). From the pole-zero diagrams and frequency responses, it can be concluded that the stability and the frequency of the filter are working properly.

III. Experiments and Results

First, MATLAB program is developed to read the ECG signal from the database. Then, the power line interference for 50 Hz and 60 Hz is modeled using Equation (1). The ECG signal is superimposed with the modeled power line interference. And the digital notch filters for the power line interference were designed and implemented according to the design specifications. The filter was tested with the various amplitude of noise signal. The filter could also perform very well. All the works were done with MATLAB. The filter eliminates the noise well as shown in Fig. (5), (6), (7) and (8).

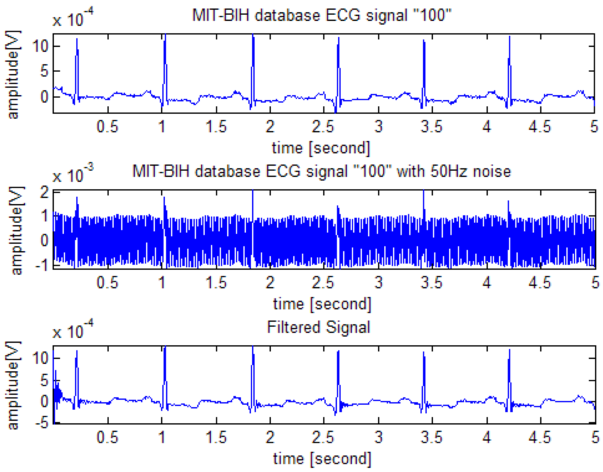

Fig. 5 ECG signal "100" from database (1st row), ECG signal superimposed with 50 Hz nose (2nd row), ECG filtered signal with 50 Hz notch filter (3rd row)

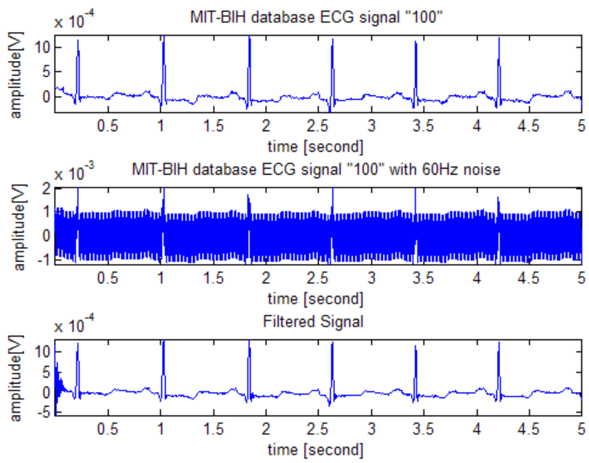

Fig. 6 ECG signal "100" from database (1st row), ECG signal superimposed with 60 Hz nose (2nd row), ECG filtered signal with 60 Hz notch filter (3rd row)

IV. Conclusion

For the post-processing of the ECG signal, to remove the power line interference is crucial for the accurate diagnosis in the computer based ECG system. Modeling of the power line interference and the application of the digital notch filter were presented in this paper. The designed notch filters were not perfect but they worked well to some extent. The results show that the important information of ECG signal (P-wave, QRS-complex, and T-wave) is not lost for further processing. The amplitude of noise signal was changed nearly up to the fifty percent of the peak to peak voltage of the ECG signal and investigated for the performance of the filter. The vital information for the ECG signal processing is not affected. The other approaches for power line interference cancellation are needed to design and applied for the optimal resolution of ECG signal. Thereafter, the results and performance of these filters are needed to compare and choose for the better solution to ECG signal analysis and reliable results. The effects of quantization on the filter performance should be considered for the further investigations. There will be a trade-off between FIR and IIR filter types for the embedded ECG machines.

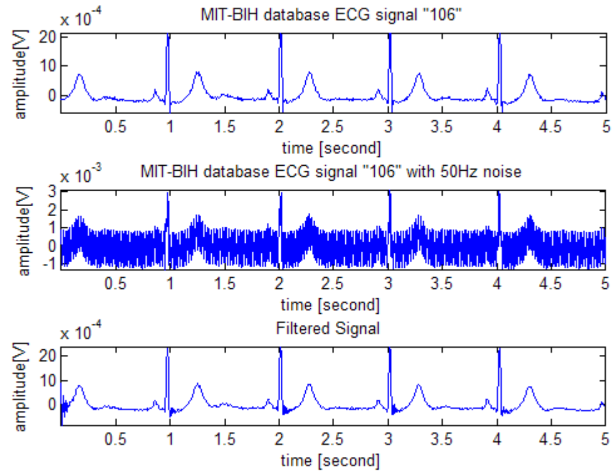

Fig. 7 ECG signal "106" from database (1st row), ECG signal superimposed with 50 Hz nose (2nd row), ECG filtered signal with 50 Hz notch filter (3rd row)

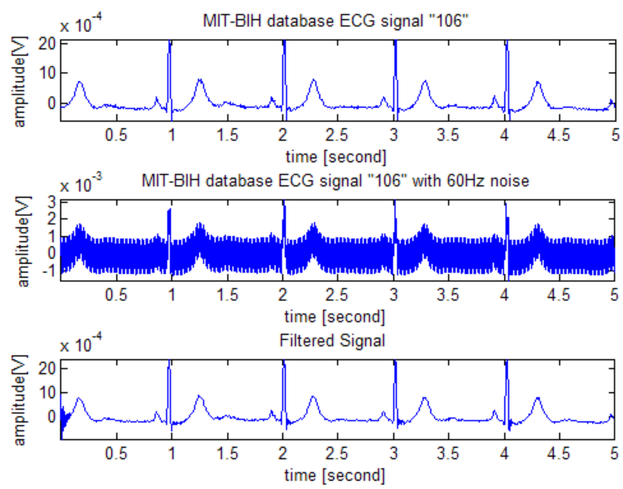

Fig. 8 ECG signal "106" from database (1st row), ECG signal superimposed with 60 Hz nose (2nd row), ECG filtered signal with 60 Hz notch filter (3rd row)

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