REDUCTION OF POWER LINE INTERFERENCE IN ECG SIGNAL USING FIR FILTER

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Abstract-

Filtering of power line interference is very meaningful in the measurement of biomedical events recording, particularly in the case of recording signals as weak as the ECG. The available filters for power line interference either need a reference channel or regard the frequency as fixed 50/60Hz. Methods of noise reduction have decisive influence on performance of all electro-cardio-graphic (ECG) signal processing systems. This work deals with problems of power line interference reduction. Some analogue and digital approaches to this problem are presented and its properties, advantages and disadvantages are shown. Present paper deals with design and development of digital FIR equiripple filter. The basic ECG has the frequency range from .5Hz to 100Hz.

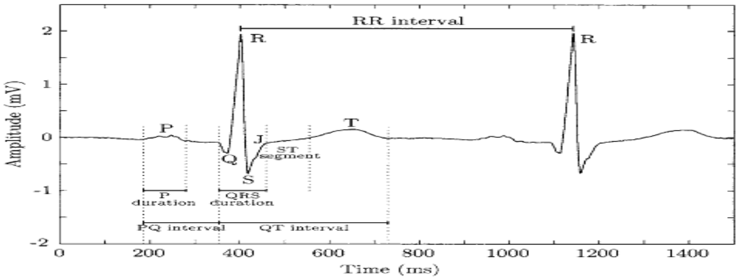
Keywords- Electrocardiogram, Simulation, Equiripple Filter, Real Time Filtering, Noise reduction.

I. Introduction

Signal processing, in general, has a rich history, and its importance is evident in such a diverse fields as biomedical engineering, acoustics, Sonar, radar, Seismology, speech communication, data communication, nuclear science, and many others. In many applications, for example, in EEG and ECG analysis or speech processing it can be used to extract some characteristic parameters. Alternatively, to remove interference, such as noise, from the signal or to modify the signal to present it in a form this is more easily interpreted by an expert. The field of biomedical signal analysis or processing has advanced to the stage of practical application of signal processing and pattern analysis techniques foe efficient and improved noninvasive diagnosis, online monitoring of critical patients, and rehabilitation and sensory aids for the handicapped. Techniques developed by engineers are gaining wider acceptance by practicing clinicians, and the role of engineering in diagnosis and treatment is gaining much–observed respect. The major strength in the application of computers in biomedical signal analysis lies in the potential use of signal processing and modeling technique for the quantitative or the objective analysis. Analysis of signals by human observers is almost always accompanied by perceptual limitations, inter-personal variations, errors caused by fatigue, errors caused by the very low rate of incidence of certain sign of abnormality, environmental distortions, and so on.

Electrocardiogram (ECG) is an important clinical tool for investigating the activities of heart, which is one of the signals of vitality. Interpretation of these details allows diagnosis of a wide range of heart conditions. These conditions can vary from minor to life threatening. A typical ECG tracing of a normal heartbeat (or cardiac cycle) consists of a P wave, a QRS complex and a T wave. Figure 1 shows the typical ECG trace.

Figure 1: Typical ECG trace.



The electrical activity of the heart is generally sensed by monitoring electrodes placed on the skin surface. The electrical signal is very small (normally 0.0001 to 0.003 volt). These signals are within the frequency range of 0.05 to 100 Hertz (Hz.) or cycles per second. Unfortunately, other artifactual signals of similar frequency and often larger amplitude reach the skin surface and mix with the ECG signals. Artifactual signals arise from several internal and external sources. Means Electro-cardio-graphic signals (ECG) may be corrupted by various kinds of noise. Typical examples are:

1. Power line interference
2. Electrode contact noise.
3. Motion artifacts.
4. Muscle contraction.
5. Base line drift.
6. Instrumentation noise generated by electronic devices.
7. Electrosurgical noise.

From various artifacts contaminate electrocardiogram (ECG) recording, the most common are power line interference and baseline drift. Power line interference is easily recognizable since the interfering voltage in the ECG may have frequency 50 Hz. The interference may be due to stray effect of the alternating current fields due to loops in the patient's cables. Other causes are loose contacts on the patient's cable as well as dirty electrodes. When the machine or the patient is not properly grounded, power line interference may even completely obscure the ECG waveform. The most common cause of 50 Hz interference is the disconnected electrode resulting in a very strong disturbing signal, and therefore needs quick action. Electromagnetic interference from the power lines also results in poor quality tracings. Electrical equipments such as air conditioner, elevators and X-ray units draw heavy power line current, which induce 50 Hz signals in the input circuits of the ECG machine. Electrical power systems also induce extremely rapid pulse or the spike on the trace, as a result of switching action. Care should be taken to suppress these transients. Figure 2 shows the ECG signal with power line interference.

For the meaningful and accurate detection, steps have to be taken to filter out or discard all these noise sources. Analog filters help in dealing with these problems; however, they may introduce nonlinear phase shifts, skewing the signal. Also, the instrumentation depends on resistance, temperature, and design, which also may introduce more error. With more recent technology, Digital filters are now capable of being implemented offering more advantages over the analog one. Digital filters are more precise due to a lack of instrumentation. The work on design and implementation of Digital filter on the ECG signal is in progress in the different part of the world.

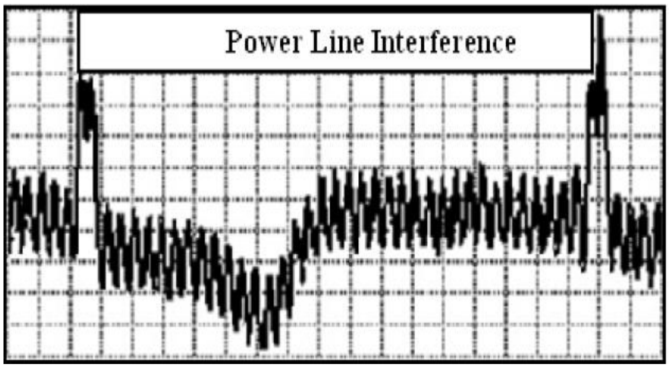


Figure 2: ECG corrupted Due to Power line Interference.

Many researchers have worked on development of method for reduction of noise in ECG signal. Choy TT, Leung P M. have used 50 Hz notch filters for the real time application on the ECG signal it is found that filter was capable of filtering noise by 40dB.with bandwidth of4Hz and causes the attenuation in the QRS complex[3].McManus CD, Neubert KD and Cramer E have surveyed different digital filter method like notch filters, adaptive filters and globally derived filters their performances are compared on artificial signals as well as actual ECGs and found that AC interference in these ECGs is shown to exhibit two qualities especially relevant to filter design: considerable deviations from a nominal 50 Hz frequency and substantial noise at higher harmonics. For this they suggested presented different digital filter methods to eliminate it [1].Cramer E, McManus CD, and Neubert D have introduced Global filtering of AC interference in the digitized ECG as a new concept. Two different filters embodying a global approach are developed. One is based on a least-squares error fit, the other uses a special summation method. Both methods are compared with a local predictive filter by applying each filter to artificial signals and to real ECGs [4].Some researchers have used analog filters for removal of the power line interference. Hejjel L, used the analog digital notch filter for the reduction of the power line interference in the ECG signal for the heart rate variability analysis. The investigation addressed the analysis of the effects of AC interference and its filtering on the precision and accuracy of heart rate detection. Artificial ECG recordings with predefined parameters were simulated by a computer and a data acquisition card, consecutively filtered by an analog notch filter. It is found that the filtering of uncorrupted ECG signals does not result in heart rate period deviations. Power-line interference contamination proportionally alters the accuracy of representative point detection. Literature encouraged using the digital notch filter for the power line contamination removal [5].

Mihov G, Dotsinsky IV and Georgieva TS described the subtraction procedure for the power line interference removal in the ECG signal. In contrast to the well-known hardware and software filters, the procedure does not affect the signal frequency components around the rated power line frequency. Originally, the procedure was developed for multiplicity between the sampling rate and the interference frequency. The implementation of the subtraction procedure can be extended to almost all possible cases of sampling rate and interference frequency variation. The work was initially carried out in a MATLAB environment and latter on programs have been written in C + + language for DSPs [6]. Hamilton PS had worked on the application of the adaptive and non-adaptive digital filter on the ECG signal. He worked for the performance evaluation based on two implementations of the notch filters based on transient response time, signal distortion, and implementation complexity. Before filtration and after filtration results are given in the literature [7]. Sander A. et. al. designed and implemented a digital notch filter. A 50/60 Hz notch filter system was designed to eliminate power line interferences from the high-resolution ECG. This special filter causes only minimal distortions of the power spectra and thus permits us to filter high-resolution ECG's without any appreciable changes in the frequency distribution of the original signal. Since the filter is based on an integer coefficient filter technique, the calculation time is relatively short and the programming effort comparatively low [8]. Kumaravel N et.al. suggested the power line interference removal technique to enhance the signal characteristics for diagnosis. They suggested the performances of the linear FIR filter, Wave digital filter (WDF) and adaptive filter for the power-line frequency variations from 48.5 to 51.5 Hz in steps of 0.5 Hz. The performances of Rule-based FIR filter and Rule-based Wave digital filter are compared with the LMS adaptive filter. They found the adaptive filter more effective than the rule base filtering technique [9]. Wu Y, Yang Y, discussed the advantages and disadvantages of several conventional digital filter methods. Then, based on Levkov method, they proposed a new filter method. By using these methods to remove 50 Hz interference from more than 50 persons' ECG signals, results show that this new method is the best, and it can satisfy the real time requirement of digital ECG machine [10]. Van Alste JA et.al. suggested the application of an efficient FIR filter with reduced number of taps for the removal of the base line wonder and power line interference in the ECG [11]. Mitov IP described a method for reduction of power line interference (PLI) in electrocardiograms with sampling rate integer multiple of the nominal power line frequency and tested using simulated signals and records from the databases of the American Heart Association and the Massachusetts Institute of Technology. The method involves parabolic detrending of the ECG, estimation of the signal components with frequencies corresponding to PLI by discrete Fourier transform, and minimum-squared-error approximation of decimated series of averaged instantaneous values of PLI using appropriately defined weights. The main advantage of the developed method in comparison with other simpler and faster approaches is the accurate interference reduction in cases when the power line frequency deviates from the nominal 50 or 60 Hz. That means the track on the variation on the frequency has been kept. Due to computational burden, the method is more suitable for off-line application instead of the on line method [12]. Ziarani AK and Konrad A. suggested the adaptive digital filtering method for the power line interference reduction. This method employs, as its main building block, a recently developed signal processing algorithm capable of extracting a specified component of a signal and tracking its variations over time. Design considerations and performance of the method are with the aid of computer simulations. Superior performance is observed in terms of effective elimination of noise under conditions of varying power line interference frequency. This method is a simple and robust structure which complies with practical constraints involved in the problem such as low computational resource availability and low sampling frequency [13]. Dotsinsky I, Stoyanov T have assessed the efficiency of notch filters and a subtraction procedure for power-line interference cancellation in electrocardiogram (ECG) signals. In contrast with the subtraction procedure, widely used digital notch filters unacceptably affect QRS complexes [14]. Ider YZ, Saki MC, Gcer HA described a method for line interference reduction to be used in signal-averaged electrocardiography (SAECG) systems and its performance is analyzed. This new method is an adaptation of a different technique for removal of line interference from conventional electrocardiograms. It involves the recording of a line interference signal simultaneous with the lead signals, so that a shifted and scaled version of it can be used to subtract line interference from the leads. It is seen that this line interference subtraction method can reduce line interference effectively and without introducing any additional noise into the ECG signal [15]. Ider YZ, Koymen H. Suggested a theory that power line frequency must be accurately known if line interference is to be accurately subtracted from the output of a bi-potential amplifier[16].

There are different methods like window method and equiripple method also available [17]. The simplest technique is known as "Windowed" filters. This technique is based on designing a filter using well-known frequency domain transition functions called "windows". The use of windows often involves a choice of the lesser of two evils. Some windows, such as the Rectangular, yield fast roll-off in the frequency domain, but have limited attenuation in the stop-band along with poor group delay characteristics. Other windows like the Blackman, have better stop-band attenuation and group delay, but have a wide transition-band (the band-width between the corner frequency and the frequency attenuation floor). Windowed filters are easy to use, are scalable.

Ii. Design Of Fir Notch Filter

FIR filters are widely used due to the powerful design algorithms that exist for them, their inherent stability when implement in non-recursive form, the ease with which one can attain linear phase, their simple extensibility to multirate cases, and the ample hardware support that exists for them among other reasons.

A. Design of Equiripple notch filter:

Linear-phase equiripple filters are desirable because they have the smallest maximum deviation from the ideal filter when compared to all other linear-phase FIR filters of the same order.

An Equiripple or Remez Exchange (Parks-McClellan) design technique provides an alternative to windowing by allowing the designer to achieve the desired frequency response with the fewest number of coefficients. This is achieved by an iterative process of comparing a selected coefficient set to the actual frequency response specified until the solution is obtained that requires the fewest number of coefficients. Though the efficiency of this technique is obviously very desirable, there are some concerns. For equiripple algorithms some values may converge to a false result or not converge at all. Therefore, all coefficient sets must be pre-tested off-line for every corner frequency value.

Equiripple designs are based on optimization theory and require an enormous amount of computation effort. With the availability of today's desktop computers, the computational intensity requirement is not a problem, but combined with the possibility of convergence failure.

B. Design of Least Square notch filter:

Equiripple designs may not be desirable if we want to minimize the energy of the error (between ideal and actual filter) in the pass/stop band. Consequently, if we want to reduce the energy of a signal as much as possible in a certain frequency band, least-squares designs are preferable.

III. Performance Measures

The efficiency of FIR filter based de-noising is measured by evaluating SNR of enhanced ECG signal. SNR of denoised ECG signal is given by

$$SNR = 10\log_{10}\frac{\sum(x_{denoised})^2}{\sum(x_{org}-x_{denoised})^2} \qquad (1)$$

In which x_{org} is raw ECG signal and $x_{denoised}$ is filtered ECG signal.

IV. Results

On implementation of above designed filters on ECG signals with powerline interference, the following results are obtained.Fig 3 shows the results for Equiripple notch filter. Fig 4 shows the results for Least square filter.Table1. shows the results of comparison for different FIR filter design.

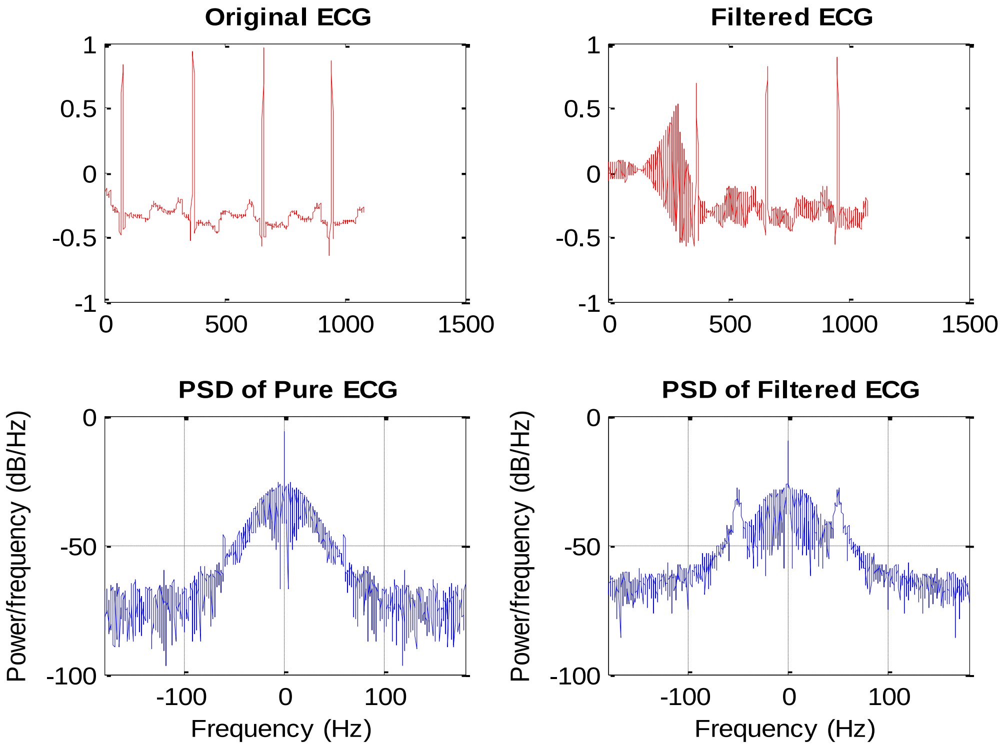


Figure 3: Results for Equiripple notch filter.

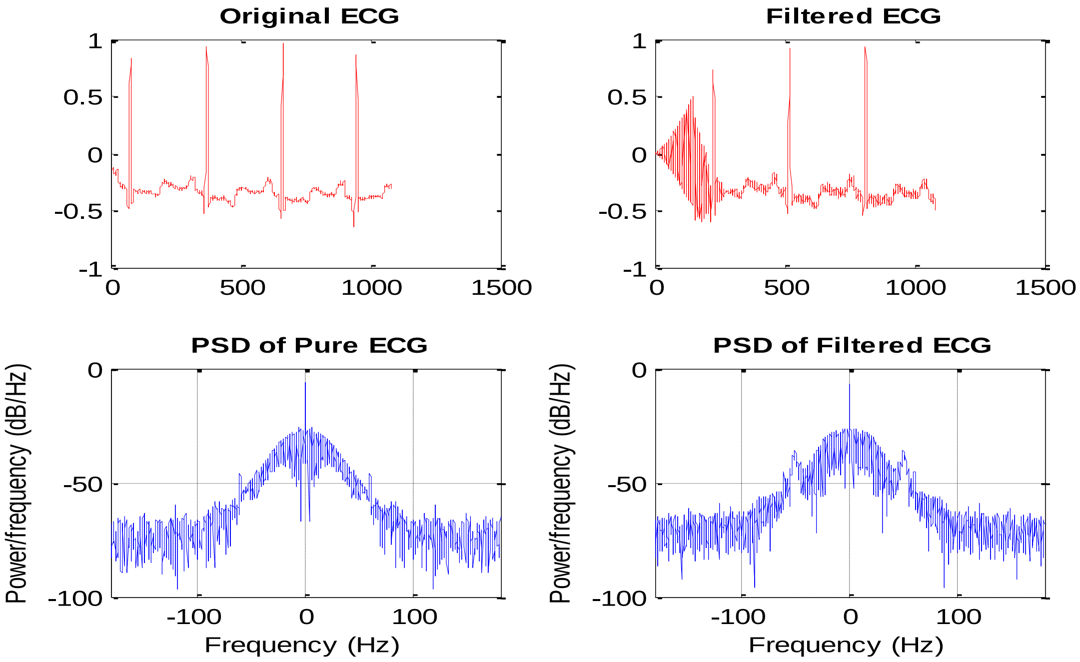


Figure 4: Results for Least square filter.

V. Conclusion

The Finite Impulse Response [FIR], filter produces the impulse response which has a limited number of terms. These types of filters are generally realized non recursively, which means that there is no feedback involved in computation of the output data. The output of the filter depends only on the present inputs. FIR filters based on equiripple design have been designed and implemented. Table 1 shows the comparison of the present work with other known methods .In comparison with the window method reduction in signal power of 50 Hz is more in the Equiripple and Least squares methods. In the window method the numbers of elements required are less while in equiripple method more computational elements are required therefore computational time is the major difficulty of the equiripple type digital filter implemented on the noisy ECG signal. Method is cost effective and flexible.

TABLE I. Comparison for Different Fir Filter Design Techniques

Type of FIR Filter	Filter order	Output SNR	Adder	Delay units
Equiripple	582	7.1544	581	581
Least Square	298	5.069	298	297
Bartlett	298	-4.873	298	298
Blackman	298	-5.9249	298	298
Hamming	298	-4.217	298	298
Hann	298	-10.3437	298	298
Rectangular	298	3.8913	298	298
Kaiser	298	1.9241	298	298

References

[1] McManus CD, Neubert KD, Cramer E, “Characterization and elimination of AC noise in electrocardiograms: a comparison of digital filtering methods”, Comput Biomed Res. 1993 Feb;26(1):48-67.

[2] Ch. Yu, G. Li, L. Lin, Stephen C-Y. Lu, “The Realization of Tracking Power-line Interference Adaptive Coherent Model Based on Part FFT”, *Journal of Physics: Conference Series 13* (2005) 274–279.

[3] Choy TT, Leung PM., “Real time microprocessor-based 50 Hz notch filter for ECG”,*JBiomedEng*.1988May;10(3):285-8.

[4] Cramer E, McManus CD, Neubert D, “Estimation and removal of power line interference in the electrocardiogram: a comparison of digital approaches”, *Comput Biomed Res.* 1987 Feb;20(1):12-28.

[5] Hejjel L, “Suppression of power-line interference by analog notch filtering in the ECG signal for heart rate variability analysis: to do or not to do?”, *Med Science Monit.*2004Jan; 10(1):MT6-13.

[6] Mihov G, Dotsinsky IV, Georgieva TS, “Subtraction procedure for powerline interference removing from ECG: improvement for non-multiple sampling”, *J Med Eng Technol.* 2005 Sep-Oct;29(5):238-43.

[7] Hamilton PS, “A comparison of adaptive and nonadaptive filters for reduction of power line interference in the ECG”, *IEEE Trans Biomed Eng. 1996* Jan; 43(1):105-9.

[8] Sander A, Voss A, Griessbach G, “An optimized filter system for eliminating 50 Hz interference from high resolution ECG”, *Biomed Tech (Berl). 1995* Apr; 40(4):82-7.

[9] Kumaravel N, Senthil A, Sridhar KS, Nithiyanandam N, “Integrating the ECG power-line interference removal methods with rule-based system”, *Biomed Sci Instrum. 1995*; 31:115-20.

[10] Wu Y, Yang Y “A new digital filter method for eliminating 50Hz interference from the ECG”, *Zhongguo Yi Liao Qi Xie Za Zhi.* 1999 May; 23(3):145-8.

[11] Van Alste JA, Schilder TS, “Removal of base-line wander and power-line interference from the ECG by an efficient FIR filter with a reduced number of taps”, *IEEE Trans Biomed Eng. 1985* Dec; 32(12):1052-60.

[12] Mitov IP., “A method for reduction of power line interference in the ECG”, *Med Eng Phys. 2004* Dec;26(10):879-87.

[13] Ziarani AK, Konrad A, “A nonlinear adaptive method of elimination of power line interference in ECG signals”, *IEEE Trans Biomed Eng. 2002* Jun;49(6):540-7.

[14] Dotsinsky I, Stoyanov T, “Power-line interference cancellation in ECG signals”, *Biomed Instrum Technol. 2005* Mar-Apr;39(2):155-62.

[15] Ider YZ, Saki MC, Gcer HA, “Removal of power line interference in signal-averaged electrocardiography systems”, *IEEE Trans Biomed Eng.* 1995 Jul;42(7):731-5.

[16] Ider YZ, Koymen H, “A new technique for line interference monitoring and reduction in biopotential amplifiers”, *IEEE Trans Biomed Eng.* 1990 Jun; 37(6):624-31.

[17] Mahesh S. Chavan, RA. Agarwala, M.D.Uplane, “Design and implementation of Digital FIR Equiripple Notch Filter on ECG Signal for removal of Power line Interference”, WSEAS TRANSACTIONS on SIGNAL PROCESSING, Volume 4, April 2008