FILTERING TECHNIQUES FOR ECG SIGNAL PROCESSING

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ABSTRACT

ECG is the graphical recording of the electrical activity of the heart and recognized biological signal used for clinical diagnosis. The ECG signal is very sensitive in nature, and even if small noise mixed with original signal the various characteristics of the signal changes. The signal voltage level is as low as 0.5 to 5mV and is susceptible to artifacts that are larger than it. The frequency components of a human's ECG signal fall into the range of 0.05 to 100Hz and as far as the noise is concerned; the muscle movements, mains current and ambient electromagnetic interference generate it. Hence filtering remains an important issue, as data corrupted with noise must either filter or discarded. This paper discusses different filtering techniques used in ECG signal preprocessing and their implementation in a wide variety of systems for ECG analysis in recent research work.

Keywords: *Electrocardiogram, ECG Signal Processing, Artifact, Filtering*

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I. INTRODUCTION

Electrocardiogram (ECG) consists of graphical recording of electrical activity of the heart over time. It is most recognized biological signal, and with non-invasive method; it is commonly used for diagnosis of some diseases by inferring the signal. Cardiovascular diseases and abnormalities alter the ECG wave shape; each portion of the ECG waveform carries information that is relevant to the clinician in arriving at a proper diagnosis. The electrocardiograph signal taken from a patient is generally get corrupted by external noises, hence necessitating the need of a proper noise free ECG signal. A signal acquisition system, consist of several stages, including: signal acquisition though hardware and software instrumentation, noise or other characteristics filtering and processing for the extraction of information [Correia, S. and Miranda, J. (2009)]. Electrocardiography signals recorded on a long timescale (i.e., several days) for the purpose of identifying intermittently occurring disturbances in the heart rhythm. Simple ECG waveform shown in Fig.1. It is a combination of P, T, U wave, and a QRS complex. The complete waveform is called an electrocardiogram with labels P, Q, R, S, and T indicating its distinctive features.

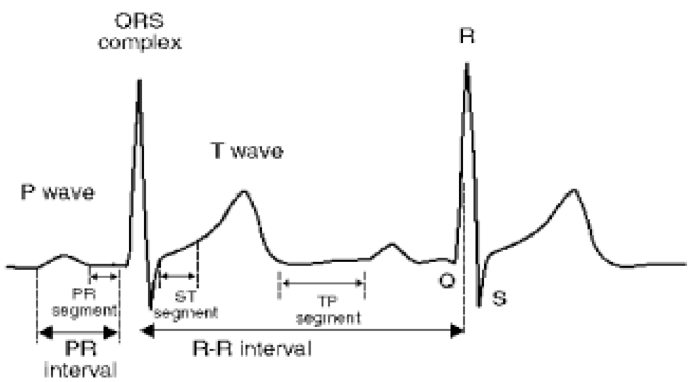

Fig.-1 Schematic representation of ECG signal

II. ECG SIGNAL PROCESSING

Signal processing is performed in the vast majority of systems for ECG analysis and interpretation. It is used to extract some characteristic parameters. Now a days biomedical signal processing have been towards quantitative or the objective analysis of physiological systems and phenomena via signal analysis. The field of biomedical signal analysis or processing has advanced to the stage of practical application of signal processing and pattern analysis techniques for efficient and improved non invasive diagnosis, online monitoring of critical ill patients, and rehabilitation and sensory aids for the handicapped. The objective of

ECG signal processing is manifold and comprises the improvement of measurement accuracy and reproducibility. ECG analysis concerns resting ECG interpretation, stress testing, ambulatory monitoring, or intensive care monitoring, which forms a basic set of algorithms that conditions the signal with respect to different types of noise and artifacts, detect heartbeats, extract basic ECG measurements of wave amplitudes and durations, and compress the data for efficient storage or transmission.

The basic ECG has the frequency range from 0.5Hz to 100Hz. artifacts removal plays the vital role in the processing of the ECG signal. It becomes difficult for the specialist to diagnose the diseases if the artifacts are present in the ECG signal

III. TYPES OF ARTIFACT IN ECG SIGNAL

The objectives of acquisition of ECG signal and signal processing system is to acquire the noise free signal. The major sources of noise are

1. Power line interference
2. Muscle contractions
3. Electrode contact noise
4. Motion Artifacts
5. Baseline wandering
6. Noise generated by electronic devices used in signal processing circuits
7. Electrical interference external to the subject and recording system
8. High-frequency noises in the ECG
9. Breath, lung, or bowel sounds contaminating the heart sounds (PCG).

There are various types of methods to extract the ECG parameters from the noisy ECG signal. First we need to analyze ECG signal to get which type of noise mesh up with the signal.

IV. ECG FILTERING: A RECENT REVIEW

The filtering techniques are primarily used for preprocessing of the signal and have been implemented in a wide variety of systems for ECG analysis. Filtering of the ECG is contextual and should be performed only when the desired information remains ambiguous. Many researches have worked towards reduction of noise in ECG signal.

Most types of interference that affect ECG signals may be removed by band pass filters; but the limitation with band pass filter is discouraging, as they do not give best result. At the same time, the filtering method depends on the type of noises in ECG signal. In some signals the noise level is very high and it is not possible to recognize it by single recording, it is important to gain a good understanding of the noise processes involved before one attempt to filter or preprocess a signal. The ECG signal is very sensitive in nature, and even if small noise mixed with original signal the characteristics of the signal changes. Data corrupted with noise must either filtered or discarded, filtering is important issue for design consideration of real time heart monitoring systems.[Himanshu, S. et al (2010)], designed amplifier using instrumentation amplifier AD620 (Analog Devices) to bring the peak value into a range of 1v; having gain of 1000. For collection of ECG signal he has used band pass filter with cutoff frequency 0.5Hz-150 Hz on NI ELVIS (National Instruments Educational Laboratory Virtual Instrumentation Suite) board.as shown in fig-2.

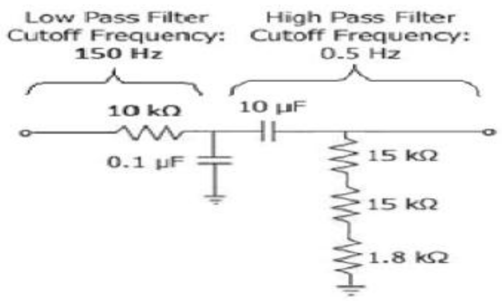

Fig.-2 Band pass filter[Himanshu, S. et al (2010)]

After the filtration the output of the analog filter is fed to the NI ELVIS. It has inbuilt data acquisition card. DAQ assistant is used to collect the signal after passing through the band pass filter. The data sampled at a rate of 1 KHz. After acquiring the signal it is processed by Butterworth (IIR) 3^{rd} order digital filter. The first digital filter is band stop filter between 49.5 to 51.4Hz to eliminate power line interference. Butterworth filter having various orders, the lowest order being the best in time domain, and higher order being better in frequency domain. It is having monotonic amplitude frequency response, which is maximally flat at zero frequency response, and amplitude frequency decreases logarithmically by increasing frequency.

The main source of baseline wandering is respiration. It is having the frequency range between 0.15 to 3Hz. They used the wavelet transform to eliminate the Baseline wandering which is an effective way to remove the signal in specified sub-bands. After the removal of baseline wandering, the resulting ECG signal is more stationary and explicit than the original signal. For removing the wideband noises, using Wavelet Denoise Express VI, which is one of the tool of ASPT [Himanshu, S. et al (2010)].

Power line interference is due to improper grounding of ECG equipment and interference from near by equipment. It is removed by using notch filter. The power line interference is more influential on the signal compared to the other types of artifact [Correia, S. et al (2009)]. The major source of such noise is electrical activity of the muscles that should be removed i.e. the noise present due to power line interface (50HZ) is also to be removed as shown in fig-3. Even though the analog amplifier having high Common Mode Rejection Ratio (CMRR), the ECG signals is contaminated by power line interference (50 HZ in India). In order to discard the sources of noise, proper filtration is required. The suppression of Baseline Wander and Power Interference can be done using digital IIR filter.

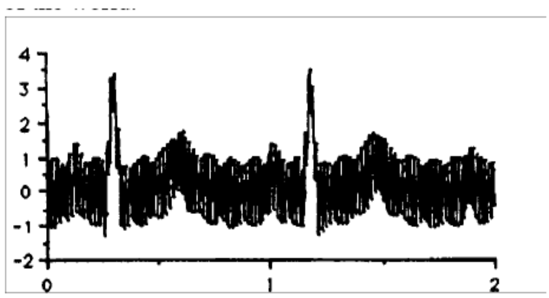

Fig.3: - ECG corrupted due to power line interference

[Padma T. et al (2009)] , used adaptive noise filtering for removal of 50 Hz that is the power line interference because, the ECG signal also contains 50 Hz signal and if normal band reject filter is used, then the 50 Hz signal which is very important in the ECG signal will be lost. Therefore by opting adaptive noise filtering, the power line frequency can be eliminated at the same time retaining the 50 Hz signal in the original waveform.

Eduardo P. et al demonstrated in such a way that the signal from the ECG leads is applied to the inputs of an instrumentation amplifier scheme with a high common mode rejection ratio. The amplified signal is then filtered using a set of active filters in order to increase the SNR (Butterworth 50 mHz high-pass filter (HPF) to diminish baseline wandering and slow motion interferences and Butterworth 150Hz low-pass filter (LPF) to diminish the EMG interference .For 50Hz interference a 10^{th} order notch digital filter was implemented as part of the digital signal processing. After analog filtering, the signal is acquired by a multifunction I/O board (NI USB-6008 with 12 bit resolution and 10 kS/s maximum sampling rate).

The hardware is developed in order to create a portable system based on a Laptop where the data acquisition device (DAQ) is USB bus-powered and the ECG conditioning circuits are powered using two 9V (2500mAh) batteries incorporated in the system (the lifetime of the batteries is large, as the power consumption is only of 25 mA). The active high-pass filter removes the baseline fluctuations; the implemented digital filtering block consists of a 150 Hz Bessel LPF and the 50Hz notch filter in order to obtain a better SNR. After digital filtering the digital signal is processed using an ECG analysis block.

[Ju-Won Lee et al (2005)] used LMS adaptive filter to filter the ECG signal, but its convergence and performance cause distortions and even poor performance, depending on the environment and the patient's condition. They proposed DSAF, which provided better performance in the experiment and hence suggested LMS adaptive filter (DSAF) applied to ECG signal processing.

[Dehghani, M. J. et al (2010)] used computer based signal processing and analysis. Baseline wandering is usually in amplitude of around 15%, full-scale deflection at a frequencies wandering between 0.15 and 0.3 Hz and a high pass digital filter can only suppress it. They used a Kaiser Window FIR high pass filter to remove the baseline wandering. They found that there are still other types of noise, which still affect the ECG signal, after removing baseline wandering. This noise may be stochastic processes within a wideband so it cannot be removed by using traditional digital filters. For removing wide band noises, undecimated wavelet transform (UWT) is applied, which has a better balance between smoothness and accuracy than the discrete wavelet transforms (DWT).

[Chavan M. S et al (2006)] designed equiripple notch filter having minimum order 580 and sampling frequency of 1000 Hz and performed using FDA tool in MATLAB. They found the reduction in signal power of 50 Hz is more in the equiripple and least squares methods when compared with the window method reduction. [Leif, S et al (2006)] designed a linear, time-invariant, high pass filter for removal of baseline wander involving several considerations, of which the most crucial are the choice of filter cutoff frequency and phase response characteristic. The cutoff frequency should obviously be chosen so that the clinical information in the ECG signals remains undistorted while as much as possible.[Pedro R. G. et al (2007)] used two Butterworth filters in ECG acquisition system for reducing the 50 Hz noise and for eliminating the DC component of the signal and to achieve the peaks P, Q, R, S, and T without noise and their correspondent position in the array.[Heyoung Lee et al (2008)] designed a 24-hour health monitoring system in a smart house using a high pass filter with cut-off frequency 0.1 Hz. It prevents introducing drift noise in the measured signal and the notch filter removes the 60 Hz power line noise. [Patrick O. B. et al (2004)], used a 60Hz notch-filter, Texas Instruments UAF42, in the design of the signal acquisition hardware since the UAF42 has much better attenuation and sharp notch curve control than other technologies. This has resulted in major noise reduction while amplifying the ECG signal. [Yatindra et al (2010)] quantified relative performance analysis of different filtering methods for power line interface reduction and have discussed three approaches to remove noise and interference. Frequency - domain filtering (Notch Filter) to remove 50Hz component of ECG signal. Here the notch filter and other pass band, band stop filters are fixed filter, they used only limited resources and cannot change its performance according to their need. Wiener filter use the statistical characteristics for noise removing process like reference signal or secondary recorded ECG signal. They cannot change its parameter to get the optimal results, so they called it ad optimal filter. Adaptive filters are self-designing filters based on an algorithm which allows the filter to "learn" the initial input statistics and to track them, if they are time varying. The least mean square algorithm used to adjust the weights of the adaptive filter in order to minimize the error and estimate the deterministic component through filter output.

[Kenneth, K. et] al developed a more accurate and reproducible method of quantifying motion artifact in ECG (electrocardiogram) electrodes to assist in electrode assessment and design. It uses an algorithm developed by Sensor Technology & Devices Ltd. to reliably overcome the variation in results due to differing skin types and other causes of spurious readings such as reproducibility of movements used. The method combines a clear, concise experimental protocol with a software package and DSP algorithm to produce a transferable result for one pair of electrodes that can be used for comparison.

It is difficult to deal with electrical interference since it can't be filtered without compromising the ECG complex because of its similarity to the ECG signal frequency, so it is best to monitor away from other equipment, ensuring cable and lead wires do not cross the power cables of other equipment or vent tubing. To reduce muscle tremor and patient movement, attempt to warm a shivering patient or make them more comfortable in a reclined position, if possible, rather than adjust a filter setting and then continually check lead wire-to-electrode connection and electrode-to-patient's skin adhesion to ensure ECG quality and prevent false alarms. It is important to select a suitable lead that shows the largest amplitude and cleanest signal so that a QRS complex and R-wave, in particular, can be accurately detected by the monitor. Clinicians depend on the monitors they use every day to provide accurate and useful information. When it comes to ECG quality, the electrode type, electrode application, and skin preparation are factors that play an important role in sending a good ECG signal to the monitor for analysis.

V. CONCLUSION

Technological advances in communication and low power circuit design have enabled the development of better, safer ECG devices with a capacity to incorporate the latest diagnostic features. But the issue of the sensitivity of ECG signal getting distorted by even a small noise makes the study of ECG filtering along with the various types of filters very significant .Hence the acquisition and analysis of ECG signal still remain a challenging task, despite technological advances. But further study and research should continue to develop cost effective and flexible methods of ECG filtering with improved performance of various filters applied to ECG signal processing.

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