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FILTERING MATERNAL AND FETAL ELECTROCARDIOGRAM (ECG) SIGNALS USING SAVITZKY-GOLAY FILTER AND ADAPTIVE LEAST MEAN SQUARE (LMS) CANCELLATION TECHNIQUE

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Abstract

Electrocardiogram that enrolls heart's electrical action against duration is known as a bio-electrical signal. ECG is a substantial diagnosis device for detecting heart functions. Electrocardiography is explication of electrical action of the heart after a certain time, that produces a representation of Electrocardiogram. The Electrocardiogram is a very important diagnosis device in clinical application. It is particularly beneficial in diagnosing cadence diseases, alterations in electrical transmission, and myocardial ischemia and infarction. In noninvasive electrocardiography, the signal is specified by electrodes annexed to the exterior surface of the skin and saved by an apparatus exterior to the body. Some of the most common examples of noise which the ECG filter would need to remove in order to give beneficial outcomes contains power line interference, motion artifacts, muscle contraction, electrode contact noise and interference caused due to other electronic equipment. For filtering noise assorted filters are utilized. Fetal Electrocardiogram (ECG) analysis is still a very new phenomenon. This is, partially because of deficiency of availability of gold canonical databases, partially because of comparatively low SNR of fetal Electrocardiogram check against the maternal Electrocardiogram. Fetal heart proportion and its beat-to-beat variability are two significant signals about the health and status of the fetus. The observed maternal electrocardiogram (ECG) signal consists of maternal heart signal and fetal heart signal is often very noisy. Savitzky and Golay Filter gave a procedure for smoothing of datum that is situated on least-squares polynomial prediction. Adaptive Noise Canceller (Least Mean Square Algorithm) is an alternate process of forecasting signals damaged by additive noise or interference. This paper suggests De-noising methods Savitzky and Golay Filter with Adaptive Noise Canceller (Least Mean Square Algorithm) methods to help reduce the noise interference in the Maternal and Fetal ECG

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signals and better diagnose results. ECG signals are weak and easily susceptible to noise and interference.

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1 Introduction

In 1906 fetus electrocardiogram was first watched by M. Cremer. Initial work in this field was performed utilizing a galvanometer tool of that time; it was restricted to fetus signal very low amplitude. As measuring and amplification methods developed, fetus electrocardiogram was more comfortable and popular [1]. The restricting factor was then low fetus Signal Noise Ratio, particularly in asset of potent maternal cardiac interventions trouble that exists up to the present time. After several decades, with progresses in computer science and processing of signal methods, automatic processing of signal and adaptive filtration methods were utilized in order to fetus R-wave identification [2], and maternal heart attempt annulment [3, 4]. Electrocardiography is the method that used to record cardiac electrical activity for examining operation of heart muscle and neural transmission system. These electrodes specify the diminutive electrical alteration on the skin which originates from the heart muscle's electrophysiological model of depolarizing during each heartbeat. Electrocardiogram is the transthoracic explication of the electrical action of the heart over certain duration. Analysis of ECG signal maintains information concerning the status of heart. Our bodies frequently report data about our health. This data can be received through physiological materials which measure heart proportion, oxygen saturation levels, blood pressure, nerve conduction, blood glucose, brain action etc. One of the problems in biomedical data processing like electrocardiography is the separation of the wanted signal from noises caused by power line interference (PLI), external electromagnetic fields, high frequency interference and random body movements and respiration [5]. To remove signal components from unwanted frequency ranges various different types of digital filters are used. It is difficult to apply filters with fixed coefficients to reduce random noises, because human behavior is not exactly known depending on the time. Electrocardiogram (ECG) is the most important parameter for heart activity monitoring. By the full form analysis of the ECG signal a doctor can detect different types of deflections. In some applications of biomedical signal processing various useful signals are superposed by various components. Interference caused by them may have technical sources, for example:

Power line interference: This interference consists of 50 Hz harmonics mainly of sinusoidal signal.

Muscle contraction noise: The baseline of electromyogram is usually in the microvolt range which makes it insignificant.

Electrode contact noise: This noise is caused by loss of contact between the skin and electrode, which also effects the measurement of signal.

Patient movement: Patient movements are transient therefore baseline changes with the variations in the electrode skin impedance.

Electrosurgical noise: This noise completely destroys the ECG signal. It can be represented by large amplitude.

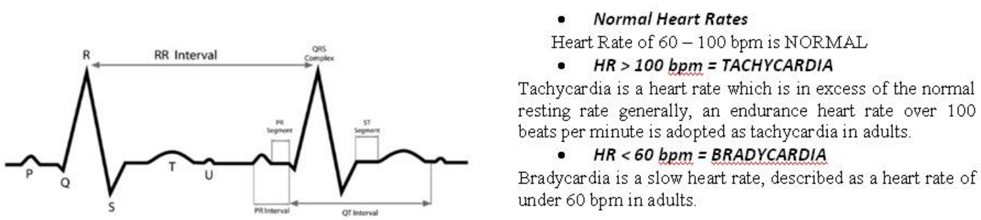

Fig 1. Shows the Standard ECG Signal

Intelligent Signal Processing(ISP) differs substantially from the classical approach to statistical signal processing in which the input-output conduct of a complex system is modeled by handling "intelligent" or "model-free" methods, rather than relying on the shortcomings of a mathematical model [6, 7, 8, 9]. Information is extracted from incoming signal and noise data, making few assumptions lacks about the statistical structure of signals and their environment. Intelligent Signal Processing discovers how ISP tools address the problems of practical neural systems [10, 11, 12, 13].

This paper is organized as follows. Section 2 describes a brief review of filtering methods applied for ECG Signal. Section 3 shows the system design for the complete system for this application. Section 4 gives the details of Savitzky-Golay Filter and Adaptive Noise Canceller (Least Mean Square Algorithm) methods. Section 5 shows the experimental results of work done and discussion and the last section will be dedicated to conclusion.

2 De-noising of ECG signal

Digital filtering methods can be utilized for developing signal quality and decreasing haphazard error noise component [14] . If we think the following equation:

$$y(t) = x(t) + n(t) \tag{1}$$

Where $x(t)$ is real signal of maternal and fetal ECG measured signal at time t, $n(t)$ is random noise affecting it, which is presumed to be additive and $y(t)$ is the received signal from Electrocardiograph. One significant problem in low-pass filtering is to separate signal from noise, since signal and noise spectra ordinarily overlap, it is not feasible to extract random noise $n(t)$ from measured signal y(t) without distorting real signal $x(t)$. The goal of this paper is to present and define a method of Savitzky-Golay filter for the de-noising of ECG signal. The Noisy ECG Signals have been created by adding the suitable noise dispersions with the reference signal. Savitzky-Golay Filter is tried firstly with WGN and then Adaptive Noise Canceller (Least Mean Square Algorithm) technique is implemented. PSNR value among real and de-noised signals are computed.

3 Methodology of research

The signal is acquired from physionet database [15]. Where we have two sets of signal the first set contains signal from mother's abdomen consisting of fetal ECG, maternal ECG and noise. In the second set we have maternal ECG taken from the mother's chest. Heartbeat of fetus is noticeably higher than mother ranging till 160 beats per minute. Fetal ECG amplitude is more feeble than that of mother's which corresponds to 0.25 millivolts peak voltage. Creating the Maternal Heartbeat Signal: The electrocardiogram shapes for both the mother and fetus have been simulated in this example. Sampling rate is 4000 Hz. The heart rate for this signal is 89 beats/min, and the peak voltage of the signal is 3.5 millivolts. Maternal Electrocardiogram: The maternal electrocardiogram signal is measured from the chest of the mother. The adaptive noise canceller removes the maternal heartbeat signal from the fetal electrocardiogram signal. To perform this task the canceller needs a reference signal generated from a maternal electrocardiogram. As the fetal electrocardiogram signal contains some additive broadband noise, so does the maternal electrocardiogram signal. Creating the Fetal Heartbeat Signal: The heart of a fetus is faster than that of its mother that is 160 and 120 beats per minute respectively. The amplitude of the fetal electrocardiogram is much weaker than that of the maternal electrocardiogram. The example shows an electrocardiogram signal having a heart rate of 139 beats per minute and a peak voltage of 0.25 millivolts for simulating fetal heartbeat. Fetal Electrocardiogram: The fetal electrocardiogram signal which is measured from the abdomen of the mother is dominated by the maternal heartbeat that propagates from the chest cavity to the abdomen. This propagation path will be described as a linear FIR filter with 10 randomized coefficients. Also, we should add a small amount of uncorrelated Gaussian noise so that we can simulate any broadband noise sources within the measurement.

For extraction of maternal and fetal ECG we utilize Savitzky & Golay Filter and Adaptive Noise Canceller by the application of two signal an input and reference. Figure 2 demonstrates the overview of the methodology of the study.

Additive White Gaussian Noise AWGN is a fundamental noise model utilized in data theory to mimic the influence of many random processes which take shape in nature. The modifiers indicate certain properties:
Additive: Because the noise will get added to your transferred signal not multi-

plied. Thus, the received signal $y(t) = x(t) + n(t)$, where $x(t)$ was original clean transferred signal, and $n(t)$ is the noise or discomfort in channel. Gaussian: This thermal noise is haphazard in nature, certainly noise can't be deterministic else you would extract deterministic noise from $y(t)$ as soon as you receive $y(t)$. Thus, this random thermal noise has Gaussian distribution with 0 mean and variance as Noise power. 0 means which anticipated value $n(t)$ during any time interval T is 0. But merely put, it additionally means which on an average $n(t)$ will take 0 value. And $n(t) = 0$ probability is the highest and probability rapidly reduces as you increase the magnitude of $n(t)$. White: meaning same amount of all the colors. Or same power for all the frequencies. That means that this noise is equally present with the same power at all the frequencies. Thus, in frequency domain, Noise level is straight along each frequency.

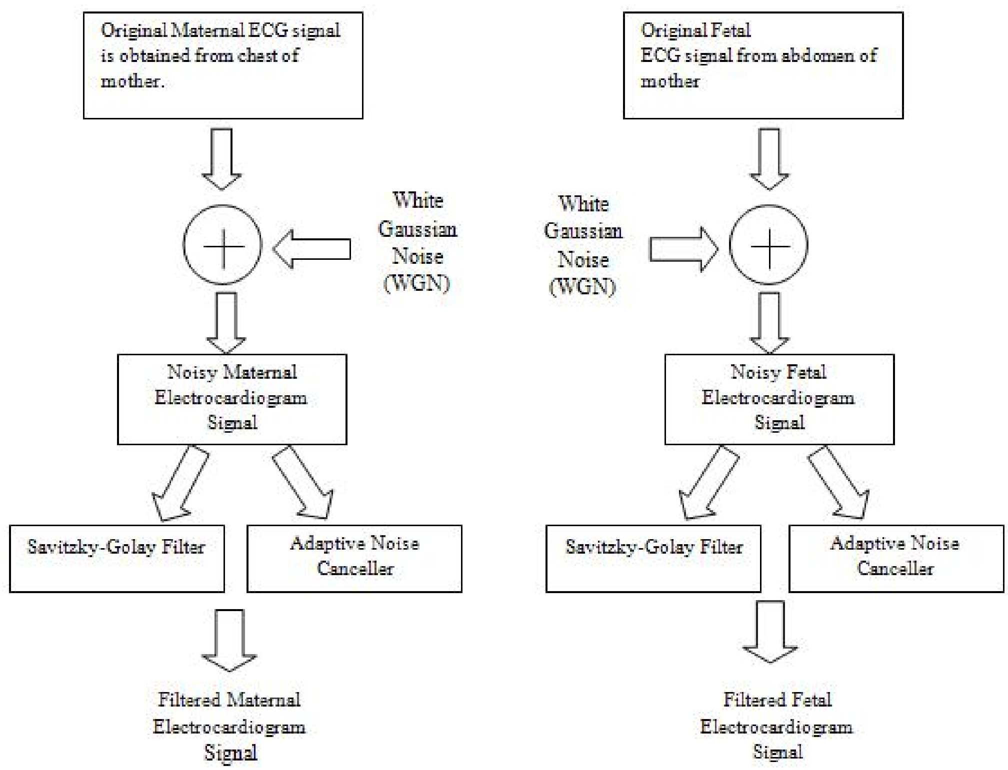

Fig 2. Overview of the complete system

It's a straightforward imperfections model of the communication channel. When you transfer certain signal into space or atmosphere or copper line to be received at other end, there are disturbances (aka noise) present in channel (space/atmosphere/copper line) because of various causes.

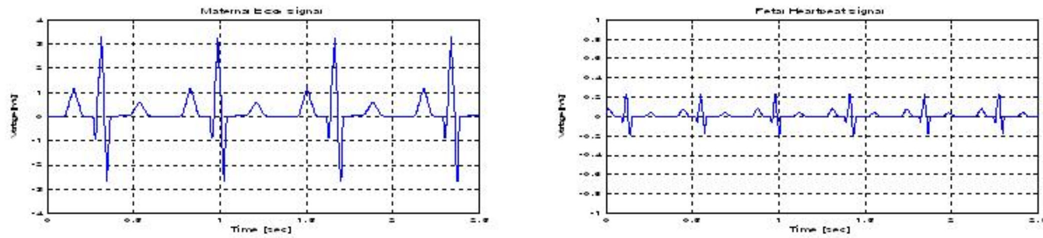

Fig 3. Representative noise free Maternal and Fetal Electrocardiogram signal

One such reason is the thermal noise by the virtue of electrons' movement in the electronic circuit being utilized for transmission and reception of signal. This disturbance or noise is modeled as Additive White Gaussian Noise.

4 Filtering techniques

In this section filtering methods Savitzky-Golay Filter and Adaptive Noise Canceller (Least Mean Square Algorithm) that is applied for this work will be described.

Savitzky-Golay Filter - The Savitzky-Golay smoothing filter was originally presented in 1964 by Abraham Savitzky and Marcel J. E. Golay in their paper Smoothing and Differentation of data by Simplified Least Squares Procedures. They found themselves often encountering noisy spectra where simple noise-reduction techniques, such as running averages, simply were not good enough for extracting well-determined characteristics of spectral peaks. The main idea presented by Savitzky and Golay was a work-around avoiding the problems encountered with running averages, while still maintaining the smoothing of data and preserving features of the distribution such as relative maxima, minima and width. *Savitzky and Golay proposed a method of data smoothing based on local least-squares polynomial approximation. They showed that fitting a polynomial to a set of input samples and then evaluating the resulting polynomial at a single point within the approximation interval is equivalent to discrete convolution with a fixed impulse response.*The advantage of the Savitzky-Golay filter is that it tends to preserve certain features of the time-series like local minima and maxima. The algorithm computes a local polynomial regression on the input data by solving the equation:

$$Y = a_0 + a_1 z + a_2 z^2 + ... + a_k z^k. \quad (2)$$

The Savitzky - Golay smoothing and differentiation filter optimally fits a set of data points to a polynomial in the least-squares sense. Savitzky and Golay have shown in their original paper that a moving polynomial fit can be numerically handled in exactly the same way as a weighted moving average, since the coefficients of the smoothing procedure are constant for all y values. Thus, Savitzky-Golay smoothing is very easy to apply. In their approach, each successive subset of $2m+1$ points is fitted by a polynomial of degree $n, (n \leq m)$ in the least-squares sense. The s-th $(0 \leq s \leq n)$ differentiation (zeroth differentiation = smoothing) of the original data at the midpoint is obtained by performing the differentiation on the fitted polynomial rather than on the original data. Finally, the running least-squares polynomial fitting can be performed simply and automatically by convolving the entire input data with a digital filter of length $2m+1$. The history and development of the SavitzkyGolay (SG) smoothing and differentiation filter have been reviewed in briefly as [16, 17];

$$G = S(S^T S)^{-1} = [g_0, g_1, ..., g_n] \,. \tag{3}$$

The matrix $G_{(2m)\times(n+1)}$ contains the convolution coefficients of the SG filter for different order differentiation at the origin (that is, the imaginary midpoint or the center of symmetry) given by the smoothing and the differentiation equations;

$$f_n(t) = \sum_{i=-m+1}^{m} h_{n,0,t,m,i} \cdot x_i \tag{4}$$

$$f_n^{(s)}(t) = \sum_{i=-m+1}^{m} h_{n,s,t,m,i} \cdot x_i. \tag{5}$$

Respectively where $f_n(t)$ and $f_n^{(s)}(t)$ are the smoothing value and the s-th $(1 \leq s \leq n)$ differentiation value evaluated at position t, with polynomial order n and data number $2m$; x_i is the original data value at point i before shifting the origin $(-m+1 \leq i \leq m)$; and $h_{n,0,t,m,i}$ and $h_{n,s,t,m,i}$ are the corresponding coefficients for smoothing and differentiation, respectively.

Adaptive Noise Cancellation Adaptive Noise Cancellation is an alternate forecasting signals method distorted by additive noise or interference. Its benefit lies in the fact that no possible signal or noise forecasts, noise levels refusal are attainable which would be hard or unfeasible to attain by other signal processing extracting noise techniques. Let N parameters of fitler at k^{th} repetition be indicated as $W_k = [w_1(k), w_2(k), \ldots, w_n(k)]^T$. For an input vector $X_k = [x(k), x(k-1), \ldots, x(k-n)]^T$ output will be given in next equation:

$$y(k) = \sum_{i=0}^{N} w_i(k) S(k-i) = W_k^T X_k. \tag{6}$$

Filters mission is to adjust its weights W iteratively to reduce Mean Square Error among primary and reference inputs. This regulation is primarily obtained by; Least Mean Square, owing to significant Least Mean Square properties: simplicity and relatively fewer computational processes, it is positive in many implementations like unknown signals approximation. LMS weights adapting algorithm can be calculated at k^{th} repetition as in next equation:

$$W_{k+1} = W_k + \mu_k e(k) X_k. \tag{7}$$

Where μ is step size coefficient that controls convergence ratio. Value of this step size should be optimized empirically to trade off convergence speed and indecision.

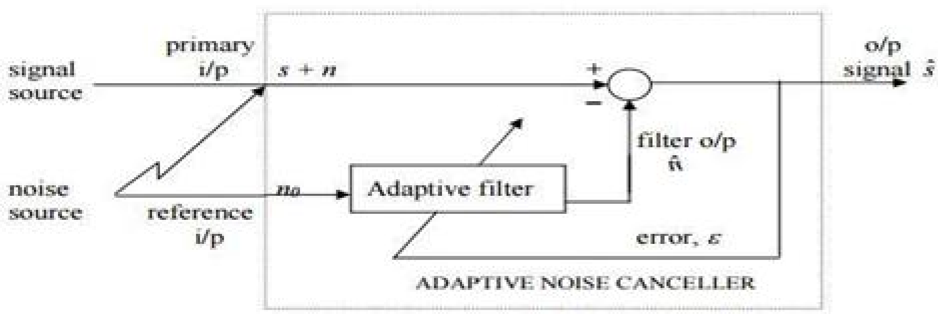

Fig 4. Basic Structure ofanAdaptive noise cancellation

5 Experiments & Results

The results of this application will be shown below; firstly the actual signal of ECG measured at time t is created then White Gaussian noise (WGN) is added as High (SNR=0 dB) and Low (SNR=40 dB). The noisy Maternal and Fetal ECG Signals are applied to Savitzky-Golay filter and Adaptive Noise Canceller (Least Mean Square Algorithm) then the resultant output is compared with Representative noise free Maternal and Fetal Electrocardiogram signal. PSNR is calculated for both cases.

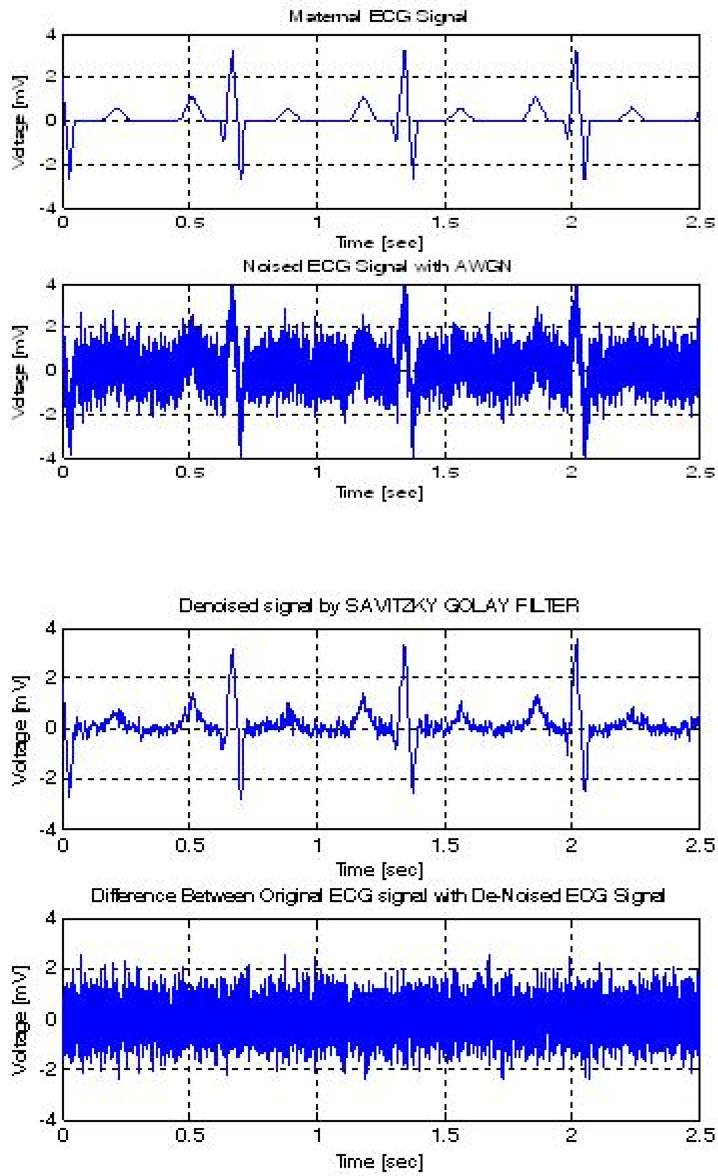

Fig 5. Maternal electrocardiogram ECG signal (Savitzky and Golay Filter SNR=0 dB (High) as a cubic filter to information frames of length 41(k=3, f=41))

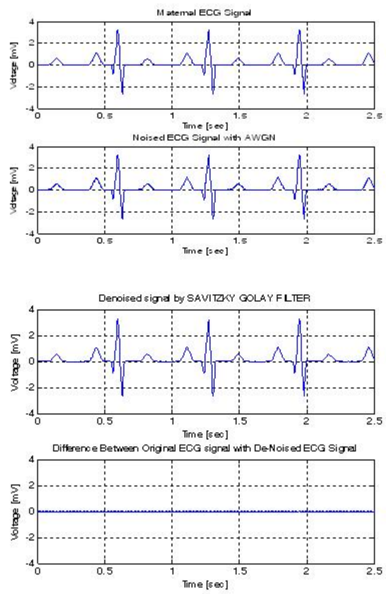

Fig 6. Maternal electrocardiogram ECG signal (Savitzky and Golay Filter SNR=40 dB (Low) as a cubic filter to information frames of length 41(k=3, f=41))

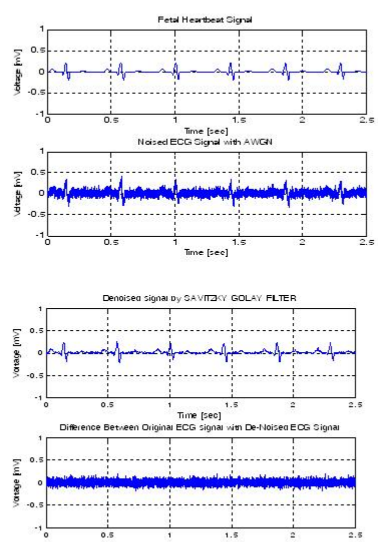

Fig 7. Fetal electrocardiogram ECG signal (Savitzky and Golay Filter SNR=0 dB (High) as a cubic filter to information frames of length 41(k=3, f=41))

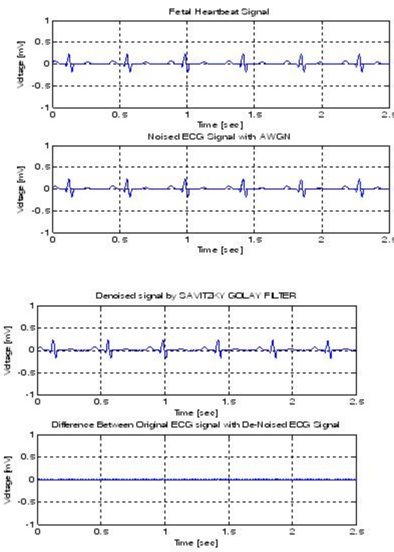

Fig 8. Fetal electrocardiogram ECG signal (Savitzky and Golay Filter SNR=40 dB (Low) as a cubic filter to information frames of length 41(k=3, f=41))

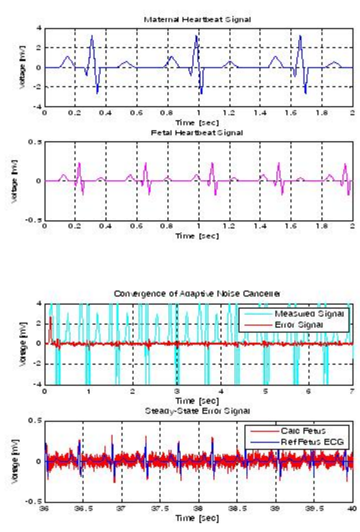

Fig 9. Maternal and fetal electrocardiogram ECG signal denoised by adaptive noise canceller (Adaptive filter length is 15 and LMS step size is 0.001.)

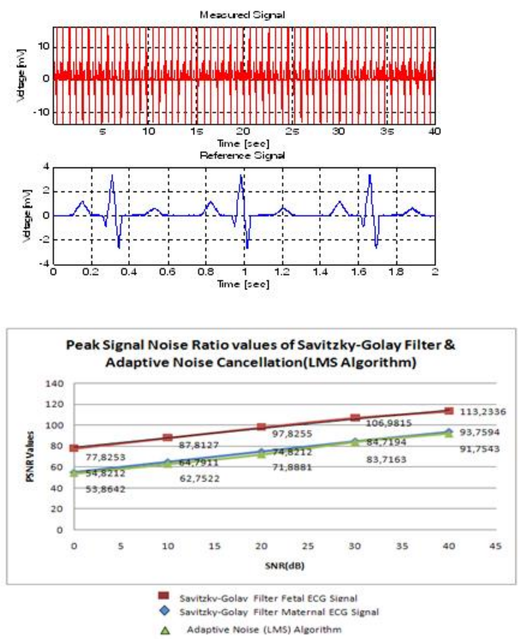

Fig 10. Peak signal noise ratio values of Savitzky-Golay Filter and Adaptive Noise cancellation (LMS Algorithm)

SNR (dB)	SAVITZKY-GOLAY FILTER (PSNR VALUE) Maternal ECG	SAVITZKY-GOLAY FILTER (PSNR VALUE) Fetal ECG	ADAPTIVE NOISE CANCELLATION (LMS: Least Mean Square Algorithm) (PSNR VALUE) Maternal - Fetal ECG
WHEN snrindB=0	PSNR = +54.8212 dB	PSNR = +77.8253 dB	PSNR = +53.8642 dB
WHEN snrindB=10	PSNR = +64.7911 dB	PSNR = +87.8127 dB	PSNR = +62.7522 dB
WHEN snrindB=20	PSNR = +74.8212 dB	PSNR = +97.8255 dB	PSNR = +71.8881 dB
WHEN snrindB=30	PSNR = +84.7194 dB	PSNR = +106.9815 dB	PSNR = +83.7163 dB
WHEN snrindB=40	PSNR = +93.7594 dB	PSNR = +113.2336 dB	PSNR = +91.7543 dB

Table 1. Peak Signal Noise Ratio (PSNR) values of Savitzky Golay Filter and Adaptive Noise Canceller (LMS: Least Mean Square Algorithm)

6 Conclusions

Heart diseases are rising in the world nowadays and they have become the primary reason of death and the Electrocardiogram is the main significant instrument to diagnose heart issues and its price is additionally low and readily existent. However Electrocardiogram signal is corrupted by many kinds of noises that influence the diagnosis and yield improper data. Numerous kinds of filters were improved to clear the noise available in Electrocardiogram and smoothing. In this Paper, two extensive and significant denoising techniques are offered and applied on actual Electrocardiogram signals corrupted with distinct amount of noise. Adaptive Noise Canceller (LMS) and Savitzky-Golay filtering are these algorithms. MATLAB Software is utilized for implementation, comparison and analysis of their noise removal performances. In this study, Adaptive Noise Canceller (LMS) and Savitzky-Golay filtering techniques of noise removal are offered and applied to real Maternal and Fetal (ECG) signals at different noise levels. The comparison indicates which Savitzky-Golay filtering performs preferable noise removal as opposed to Adaptive Noise Canceller (LMS). Savitzky-Golay extracts noise and smoothes the signal without much data loss and signal properties and individuality. Frame size and polynomial degree are Savitzky-Golay filter coefficients and all achievement is addicted to these coefficients. Savitzky-Golay aliasing (smoothing) filters are characteristically utilized to "smooth out" a noisy signal whose frequency span (without noise) is wide. In this kind of implementation, Savitzky-Golay aliasing (smoothing) filters implement much preferable than canonical mean Finite Impulse Response filters that filter an important section high signal frequency content throughout with noise. Our suggested study including the Savitzky-Golay Filter and Adaptive Noise Canceller have verified its achievment in denosing the Maternal and Fetal Electrocardiogram Signal with simulated information sets. In this work the various kinds of errors in Maternal and Fetal Electrocardiogram Signal and a solution that can be applied in Electrocardiographtools were analyzed with white Gaussian noise and outcomes. In the whole system, the primary goal will be getting clear, preferable standard output signals for good discussions. Future work will contain common and important noise reduction method discrete wavelet transform (universal and local thresholding). Its noise reduction performance will be implemented, compared and analyzed for research of Continuous Glucose Monitoring (CGM) systems. These systems are very necessary for avoiding Diabetic complications and can be very beneficial in diabetes management. For developing system class, discrete wavelet transform will be used in order to improve the influence of the system.

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