

Application of Mathematics to monitor the ECG signal

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ABSTRACT

During pregnancy, the heartbeat of mother and child can be analyzed using Fetal ECG method. The signal will be having very precise and minute information's which will be helpful to doctors during gestation. In this work, using savitzky-golay filter and adaptive noise canceller (ANC), a simple to use and well-organized methods have been implemented. For extracting FECG, the algorithm uses Fast ICA and Least Mean Square (LMS) methods. The FECG extraction method is implemented using MATLAB as a software tool. The extracted FECG signal is a noise free and exact signal. For monitoring the fetus, FECG signal recording is considered to be the best technique. It is also used for continuously monitoring the physical condition of the fetus during gestation period. FECG is a waveform which shows the overall activities of prenatal heart. FECG is obtained from a signal which is marked on the maternal womb, which is not a direct method. Abdomen signal consists of Mother's Electrocardiogram (MECG) signal, FECG signal and noise signals. Output waveform, PSNR, and Heart Rate, based on these criterions, efficiencies of all the above mentioned methods are compared. The Best technique which satisfies all the criterions is chosen.

Keywords: Maternal Heart Beat, Electrocardiogram, LMS Algorithm, Adaptive Noise Canceller, ICA, Fetal ECG extraction.

Introduction

ECG is the process of graphical recording of the Electrical potentials generated by heart. The electrical potentials are generated by continuous re polarization and depolarization of cells due to sodium and potassium ions movement in the plasma. The ECG signal range is typically 2 mv and it requires 0.1 to 120 Hz bandwidth for recording. By inserting electrodes at standard locations on the skin, ECG is acquired, which usually comes under indirect technique. HR and ECG reflects the health condition of human heart. The time period and amplitude peak of the PQRSTU wave gives us the necessary information about the health of the heart. [1, 2, 3]

FECG signal recording is one of the most excellent techniques for monitoring the Heart Signal of the fetus, which is used to continuously monitor the health condition of fetus during pregnancy period. FECG is the waveform which shows the electrical activity of Fetus's heart. In Fetal ECG, most diseases of fetus are discovered. [4]

In two different ways we can obtain FECG, they are: invasive method and noninvasive method. The invasive method may cause some problems to both mother and fetus as the electrode should pass through the abdomen of mother and then enters the womb to touch the head of fetus. Therefore nowadays noninvasive method is used for FECG recording, i.e. FECG is extracted from a signal recorded on the mother's abdomen.

Abdominal signal is comprised of Mother's ECG signal (MECG), the FECG signal and some noise signals. Noise signal mainly includes electrode's noise, muscular noise, base line's noise and recording system's noise.

Noninvasive method also has some difficulties like permanent appearance of Mother's ECG signal which dominates FECG signal as it is 5 to 20 times bigger in amplitude. This bigger amplitude signal is considered as noise in Fetal ECG extraction. For extracting FECG from AECG, there are different signal processing techniques which include adaptive filtering, Fast independent component analysis (FICA), singular value decomposition (SVD), wavelet based techniques etc.,

Need for the project

During the recording process, ECG signal is usually corrupted by the noise. The presence of different types of noises affects the signal characteristics and information. This may cause loss of information due to which it will be difficult to observe and extract the parameters which we are interested in.

This paper demonstrates two important methods which are used to filter out the noise present in the recorded data. The main purpose is to extract FECG signal using two different methods and finally through a comparative study of various parameters used in both the methods identifying a best possible and a real time method with less implementation complexity.

Objective

The objective is to separate the FECG signal from the abdomen's composite signal (MECG) which is taken from a single subject of interest in the duration of 21 to 40 weeks of pregnancy using

normalized LMS and FAST ICA filtering techniques and then performing R-peak detection for finding fetal HR. Finally, comparison of FECG extraction methods.

LITERATURE REVIEW

Number of attempts have been made for detecting the Fetal ECG signal in abdominal recordings. Those methods used either time domain signal processing or frequency domain or both. Different methods like neural networks, fuzzy logic systems, adaptive Neuro-fuzzy inference systems and genetic algorithms are also applied for obtaining the Fetal ECG signal from the MECG signal.

Marian (2007) [6] used a combined method of Projective filtering and Independent Component Analysis (ICA) to obtain the FECG. In this method the signal is assumed to be a mixture of the FECG, the MECG and noise. The main idea is using an assumption of statistical independence between the components for separating them from the mixtures and spatial decomposition of the signals. Then partially separated MECG can be enhanced by applying the projective filtering.

Zhiheng and Kaiyong (2012) [5] presented a unique method, which applies the procedure of Independent Component Analysis and wavelet transform theory for obtaining Fetal ECG from the real life sampled recordings. Wavelet de noising and wavelet de trending were used as pre-processing levels to remove various types of noise and Fast ICA algorithm is used to estimate the Fetal ECG signals. Moreover, to remove the baseline noise, two unique de trending algorithmic methods were presented.

Niknazar et al 2013 [13] introduced a Bayesian filtering framework having non linear extension for obtaining ECG signals from a uni channel which is observed in the Fetal ECG recordings from abdomen's sensor. The recorded ECG signals are implemented as the sum of multiple ECG signals. Each of the above method is explained by a dynamic nonlinear model which is earlier introduced for highly synthetic ECG. But, each ECG has a matching term in this model and even if the waves overlap in time, they can be efficiently discriminated. The parametric analysis for different kinds and values of noise limit, amplitude and HR ratios of the fetus and maternal ECGs shows its effective method for a huge set of values of these recorded parameters. They also have claimed that their method can also be estimated on the recordings of Fetal ECG from actual abdominal measurements and on actual twin Magneto cardiogram.

The methods presented above for use in extracting Fetal ECG signals have their own advantages and limitations. Some of the methods need prior knowledge for extraction, others need signals recorded from many channels and many effective algorithms including the intelligent ones (e.g., ANFIS) require Maternal ECG signal recordings carried out on the Mother's thoracic area.

Those methods require scattering of electrodes over the maternal skin and the thoracic electrodes should be used, which makes their application very inconvenient and also not comfortable in non-clinical environments such as in home care devices. Therefore it is better for developing a method to extract the Fetal ECG signal with only an abdominal lead and also without restrictions due to any particular recording technique. The configuration of single lead is having advantage for mini apparatus implementation and thus makes it satisfactory for ambulatory and long term monitoring.

METHODOLOGY

Extracting the Fetal ECG from composite signal and measurement of RR interval for finding the heart rate can be shown using the following methods. The Fig 1 demonstrates extraction of FECG using the LMS algorithm.

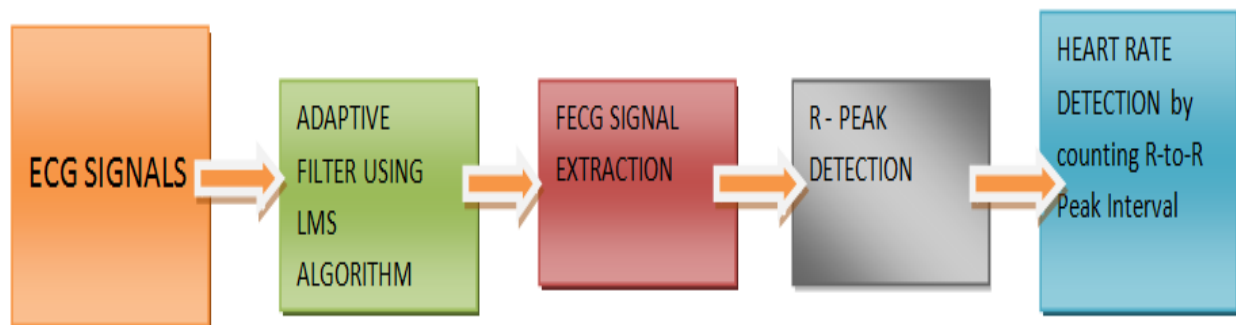


Fig 1: Block diagram of FECG Extraction using LMS algorithm

Generation of the ECG signals in MATLAB

ECG signals required for the process are generated using MATLAB and it is mainly used for simulating the shapes of electrocardiogram signal for Mother and Fetus. Heart rate of Maternal ECG signal is approximately 89 beats per minute. But the fetus's heart beats relatively faster than its mother's heartbeat, with heart rates ranges from 120 to 160 beats per minute.

Adaptive Filter algorithm

Removing the background noise and artifacts from Fetal ECG signals using an adaptive filter necessitates the application of two input signals. The primary main signal is Fetal ECG signal, which is added with Maternal ECG signal and the next secondary signal, i.e., MECG signal is treated as a reference signal is the noise which has to be cancelled [14]. This process is illustrated in the below Fig 2 which describes the Adaptive Filtering Technique.

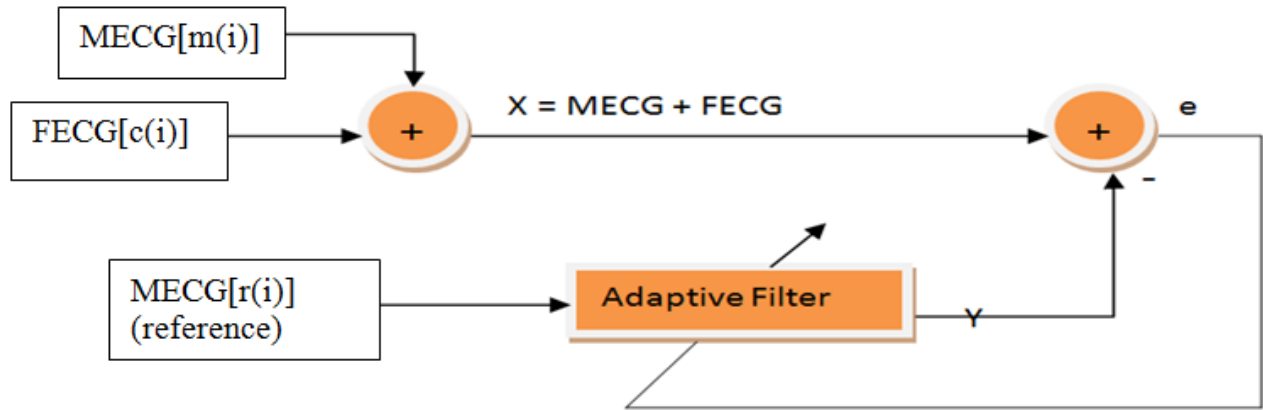


Fig 2: Block diagram of Adaptive Filtering Technique

Adaptive Filter:

An Adaptive filter is a typical system which is having a linear type of filter that has a transfer function which is supervised by variable characteristic parameters and also having a means to adjust those variable parameters in accordance with an optimization algorithm. Almost all adaptive filters are digital filters because of the complexity in implementing optimization algorithm [14].

Adaptive filters are mainly used for reducing the unwanted noise content from the sound and it is actually based on frequency content of the sound, which is nothing but our input data and the noise must be present in the background [14].

There are several important algorithms of adaptive filter, some of them are namely:

- Least Mean Square based FIR type of adaptive filter.
- Recursive Least Squares based FIR type of adaptive filter.
- FIR adaptive filter in the frequency domain.
- Affine Projection FIR type of adaptive filter.

Here $c(i)$ is the signal we are interested in. $m(i)$ is the significant maternal interference which is overlapped with the signal of interest, FECG. The Adaptive Noise Canceller's main strategy is that

it needs a second input signal, which is also known as the input reference signal $r(i)$ that has to be unassociated with signal of interest FECG and closely associated with the interference.

Adaptive filter basically adapts and learns the actual attributes of reference input signal and modifies it exactly similar to that of influencing interference which $y(i)$.

Assume that we have $c(i), r(i), m(i)$ and $y(i)$ signals, which are stationary and having zero means.

$$e(i) = x(i) - y(i) \quad (1)$$

$$e(i) = c(i) + m(i) - y(i) \quad (2)$$

Since $y(i) \cong m(i)$ (comparatively) which is the estimation of the primary noise input signal obtained at the adaptive filter's output.

By taking the square of equation 2 and its statistical average

$$E[e^2(i)] = E[c^2(i)] + E[\{m(i) - y(i)\}^2] + 2E[c(i)\{m(i) - y(i)\}] \quad (3)$$

but $m(i)$ and $y(i)$ are not correlated with signal $c(i)$

$$E[c(i)\{m(i) - y(i)\}] = E[c(i)]E[m(i) - y(i)] = 0$$

$$E[e^2(i)] = E[c^2(i)] + E[\{m(i) - y(i)\}^2] \quad (4)$$

$$\min E[e^2(i)] = E[c^2(i)] + \min E[\{m(i) - y(i)\}^2] \quad (5)$$

When $E[e^2(i)]$ is minimized, $\min E[\{m(i) - y(i)\}^2]$ is also minimized.

When $E[\{e(i) - c(i)\}^2] = 0$ output SNR is improved.

By minimizing the total output power, in turn minimizes the output noise power and maximizes the output Signal to Noise Ratio.

Normalized LMS

The modified form of the standard LMS algorithm is the Normalized LMS algorithm. The Normalized LMS algorithm effectively updates the adaptive filter's coefficients by using the below mentioned equation:

$$\vec{w}(n+1) = \vec{w}(n) + \mu e(n) \cdot \frac{\vec{u}(n)}{\|\vec{u}(n)\|^2} \quad (6)$$

It is possible to rewrite the above equation as the following equation:

$$\vec{w}(n+1) = \vec{w}(n) + \mu(n) \cdot e(n) \cdot \vec{u}(n) \quad (7)$$

Where, $\mu(n) = \frac{\mu}{\|\vec{u}(n)\|^2}$

In the earlier equation, the Normalized LMS algorithm has become the same as the standard Least Mean Square algorithm. But the only difference is that the Normalized LMS algorithm has a time varying step size i.e., $\mu(n)$. The speed of convergence of the adaptive filter can be improved through this step size.

Fetal ECG extraction using Savitzky-Golay Filter

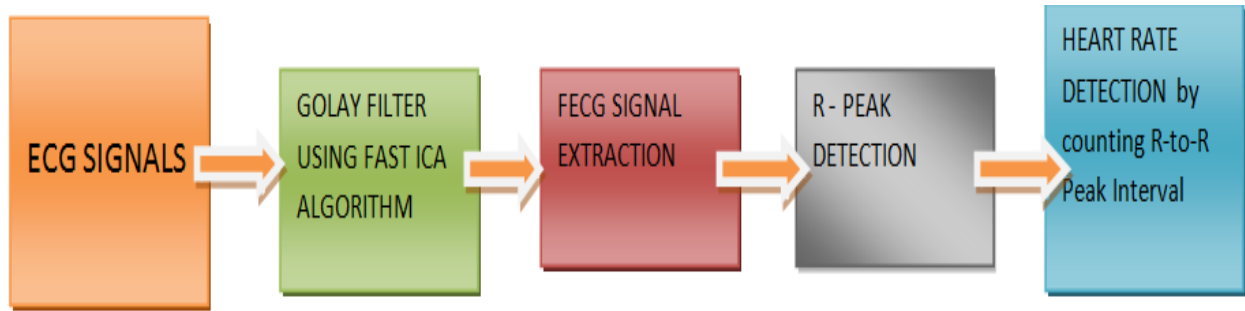


Fig 3: Block diagram of FETG Extraction using FAST ICA algorithm

Savitzky-Golay Filter using Fast ICA algorithm

Savitzky-Golay filter also known as smoothing filter performs much better than that of the standard level averaging FIR filters, which were tend to filtering out a significant and important portion of the ECG signal's high frequency content along with the noise signal. They are highly optimized in minimizing the least square errors in fitting a polynomial to each frame of the noisy data. For designing and implementing Savitzky-Golay filters, the MATLAB Signal Processing Toolbox has a function `sgolayfilt` (data, order, data points). To achieve smoothing, the number of data points must be strictly greater than the number of order undetermined coefficients [15].

Savitzky-Golay Filter:

Savitzky and Golay, together gave a method which is actually based on least mean squares polynomial method of approximation for smoothing of the data. This method mainly involves setting of a polynomial to the input sample's set and then within the interval of approximation, computes the single point polynomial which means discrete convolution whose impulse response is basically fixed [15].

Savitzky and Golay were trying to smoothen the noisy data of the chemical spectrum analyzers and they found out that least squares method of smoothing basically reduces the noise present in the signal and it maintains height and shape of the waveform peaks. Savitzky-Golay filters are used in smoothing the noisy ECG data. Shape and Peak preserving property of the Savitzky-Golay filters has proved to be very efficient for accurate ECG signal processing. Savitzky-Golay filter removes noise present in the signal of interest and without much loss of information, smoothen the signal and signal characteristics and also the originality of the signal [15].

Fast ICA Technique has been employed to extract FECG from composite mixture consisting of Maternal ECG and Fetal ECG signals.

FAST ICA algorithm

Fast ICA is a popular and an effective algorithm for method of Independent Component Analysis. Like most of the ICA algorithms, Fast ICA algorithm method requires an orthogonal rotation of the pre whitened data through a scheme of fixed point iteration, that basically maximizes the measure of non gaussianity of the rotated components. Non-gaussianity mainly serves as a proxy for statistical independence, which is a very strong condition and it requires infinite data for the verification. Fast ICA can also be derived as an approximate Newton iteration [15].

Flowchart of Fetal ECG Extraction using FAST ICA Technique

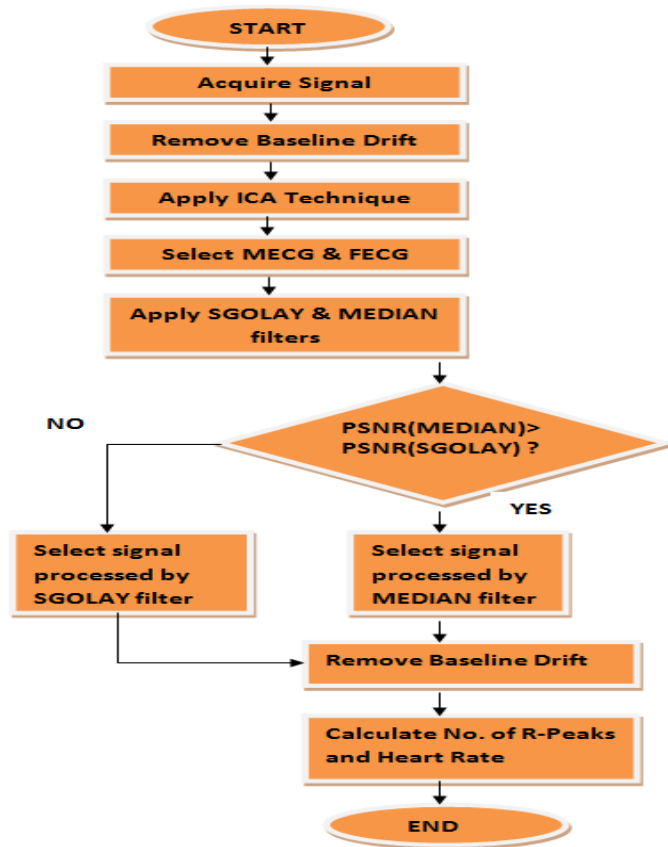


Fig 4: Operational flowchart of FAST ICA using SGOLAY and MEDIAN filters.

This work guarantees that, the Fetal ECG signal's peaks are measured properly for the detection of the R-to-R peaks. The method used is very efficient and it gives the required output which is almost accurate as the Fetal ECG heart rate.

Basically, there are three main processes involved in the flow, which are:

Data Acquisition

The main method which is used for obtaining the data is through a non-introduction of medical instruments into the body. In this process recordings are taken through the external application of electrodes. The silver chloride type of transducer is used for this purpose and electrode's positions are changed for improving good Signal to Noise Ratio (SNR). In order to obtain the signals, the Electrodes are placed over the mother's abdominal wall. The AECG signals of abdomen which we used in this process were in the format of .edf and later they are changed to the readable format of mat lab. Data Sets were taken from the database of Fetal Electro Cardiogram known as Physio net which is included in the website and is diagnosed from a single person for the duration of twenty

one to forty weeks of gestation and 10 seconds is the duration of each signal. The signals were having a resolution of 16 bits. The recorded data consists of three to four signals of abdomen and two signal types of Thorax.

Pre-Processing

Before the application of ICA procedure on the data, it would be very helpful to do pre-processing at first, which gradually reduces the complexity of ICA very effectively. Hence, it is very essential to improve the ICA method's efficiency. Whitening of data and zero mean calculation are the steps involved in the pre-processing. This method of pre-processing reduces the signals which are over estimation and it is meant for speeding the estimation process. In this procedure, the signal covariance, Eigen vector, standard deviation, is calculated.

Extraction of Signal

This process mainly consists of applying ICA algorithm technique to extract Fetal ECG from the composite mixture (AECG) consisting of Fetal and Maternal ECG. This Extraction technique is explained in detained in the further part of this document.

Post Processing

In order to improve the Signal to Noise Ratio, in post processing the median filter is used to again filter the Fetal ECG signal. Median filtering is actually a nonlinear type of operation and it is more efficient than convolution during the process of simultaneous reduction of noise and preserves the edges.

R-Peak Detection

The FETAL heart rate can be obtained through the R to R interval. The figure below shows the structure of waveform for finding R-Peaks.

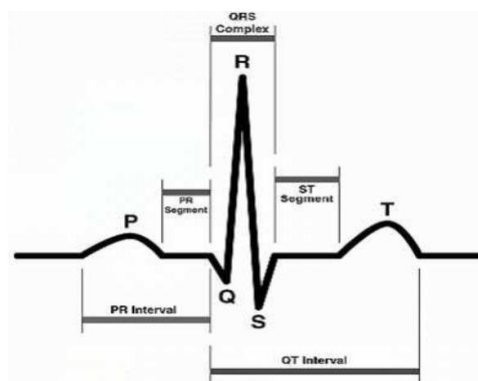


Fig 5: ECG Waveform

Fig 5 is an example of an ECG signal, which consists of a three waves namely P wave, T wave and the QRS complex. Sometimes U wave may also be visible. The P wave is generated due to the atrial contraction, the QRS complex is caused due to the contraction of the right and left ventricles, the T wave is generated due to the re-polarization of the ventricles and the U wave is considered to be a representation of the papillary muscles also called as the Purkinje fibers which results to the ventricular contraction [16].

In the automatic description of ECG signal, the automatic detection of QRS Complex in an ECG signal is the crucial step. The Accuracy of determining the R-to-R peaks and in particular QRS complex is essential in computer based analysis of ECG signal [16]. Implementing heart beat detection is the 1st step in processing the ECG signal. Heart beat refers to a single complete pulsation of the heart during the cardiac muscles contraction and then subsequently relaxation. Between two consecutive R peaks one pulsation is referred as the characteristics of ECG waveform [16].

R-Peak detection Method

HR of the Fetus is basically calculated by the number of R-peaks of FECG signal which is usually of ten seconds duration. Thus, at the very 1st using the moving RR interval method need to calculate the R-peaks in the Fetal Electrocardiogram signal by including the maximum & minimum heart rates.

1st peak detection:

By the consideration of the maximum peak, the very 1st peak is detected in the first interval of RR. Before considering it as the 1st peak, we actually look for another peak, that comes before the maximum value and also it should be more than 40% of the max value. If such peak is available in the detection process, it is considered as the 1st peak.

Next peak detection:

1st moving interval edge can be chosen as $M_n(n+50)$.

Then the 2nd moving interval edge can be obtained as:

$$SE = (RR_{max} + 2RR_{min})/2 \quad (8)$$

After the detection of 1st peak, RR interval is updated to 1st peak + 50 samples for the detection of the next peak. We renew the size of R to R interval by calculating the usual difference between two R-peaks as soon as the two R-peaks are obtained. Then on the basis of estimated average HR, we have to keep on updating the size of R to R interval when we detect more number of R peaks.

Detection of Fetal Heart Rate

Detecting the FHR primarily depends on number of R-peaks and the R to R intervals. So at first we have to find the sum of R peaks which are present in the FECG signal, then the two consecutive R peak's interval is calculated which is called as the R-R interval. Then HR in BPM is calculated by taking the average of RR interval using the below equation,

$$RR_avg = RR_sum / RR_length \quad (9)$$

$$F.H.R = 60 / RR_avg \quad (10)$$

Where,

RR_avg = average of RR interval,

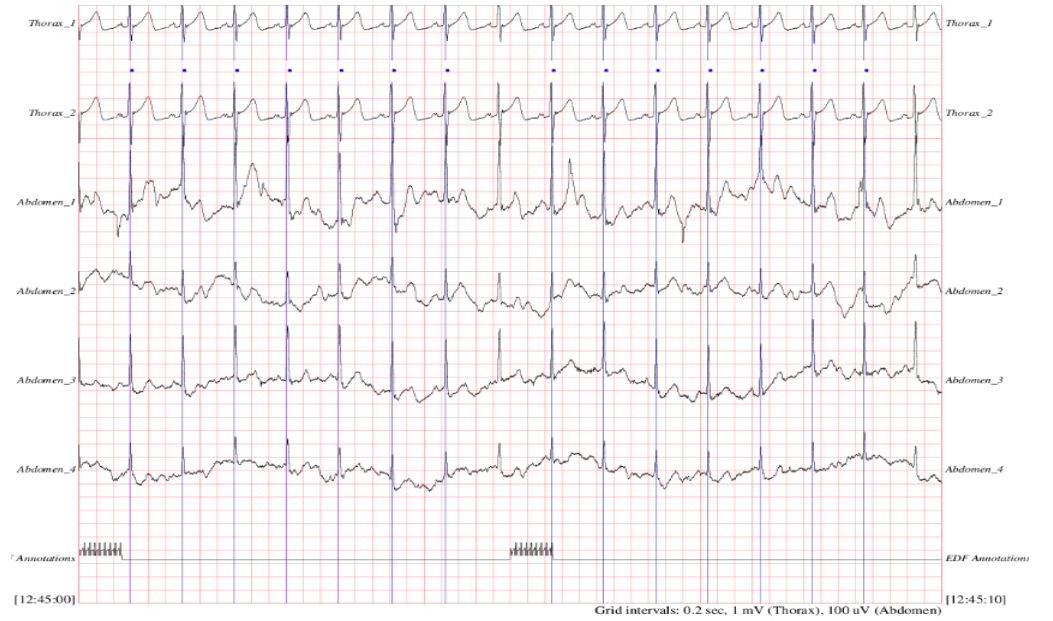
RR_sum = sum of all RR intervals,

RR_length = no. of R peaks in FECG

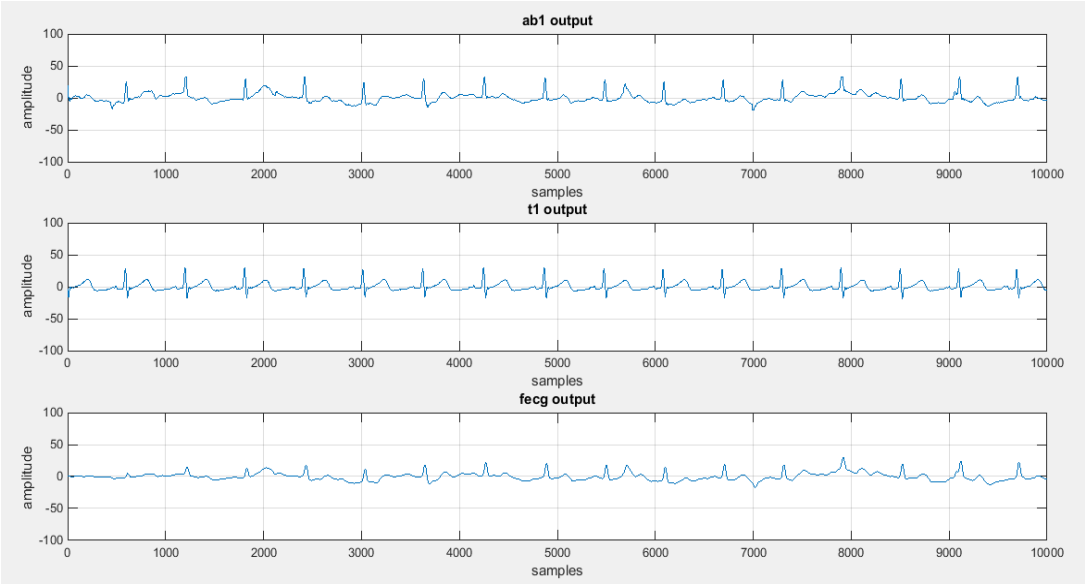
F.H.R = Fetal heart rate in beats per minute (bpm).

Results and Discussions

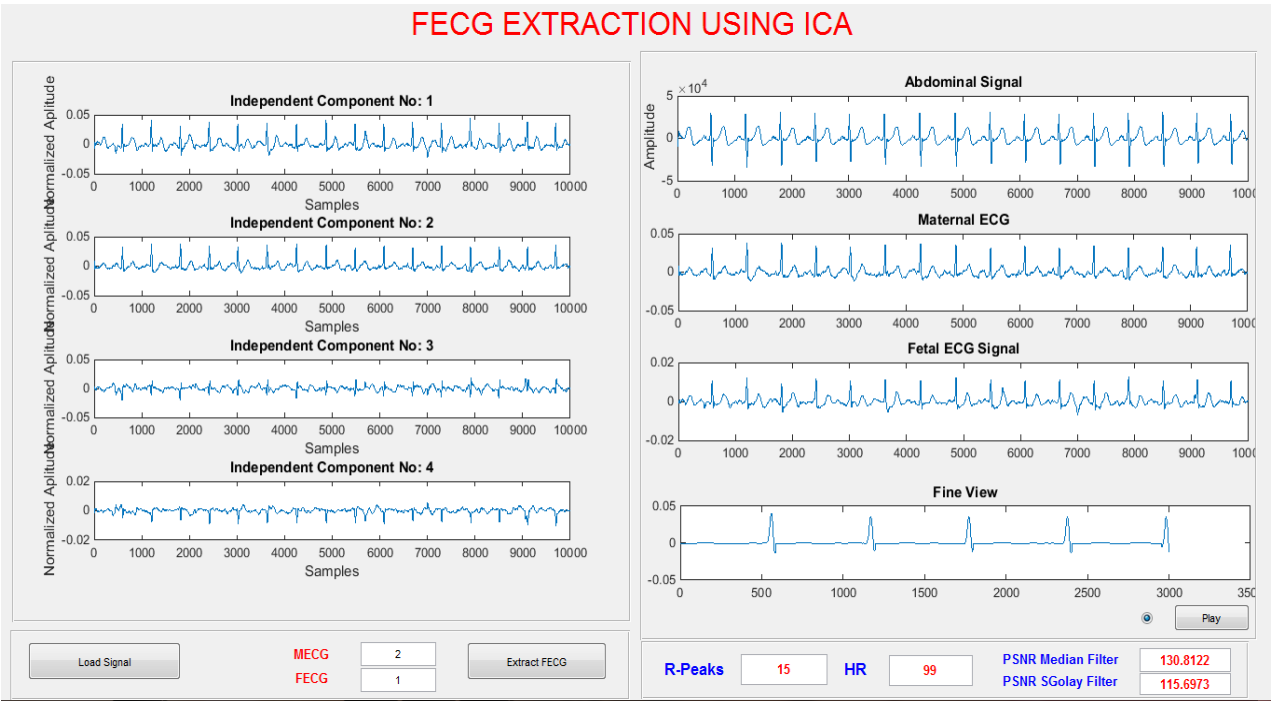
Sample-1 Input



Adaptive filter outputs using NLMS algorithm



Savitzky-Golay filter outputs using Fast ICA algorithm



CONCLUSION AND FUTURE SCOPE

CONCLUSION

This work highlights the importance on the basics of Fetal ECG, disturbances which are affecting the Fetal ECG monitoring using non-invasive techniques, Fetal ECG extraction using two different techniques and the comparative study of the difference in implementation analysis of the two techniques used. At first the paper begins with the literature analysis of some important and popular works conducted by several researchers in the field of Fetal ECG signal processing and separation. Fetal ECG morphology, Fetal ECG database and Fetal Heart Rate monitoring techniques are elaborately discussed in the paper. Different types of noises present in the mixture that affect the Fetal ECG and also described their origins. For the purpose of doing simulations, the Fetal ECG signals and other required signals are taken from the MIT-BIH/MIT Physio net database. Adaptive filter and ICA techniques are the two filtering algorithms used in this thesis.

The applied algorithm is ICA, the axes transformed are mainly based on the non gaussianity such as the fourth order moment also called as Kurtosis. The Fast ICA method is highly efficient, a real time technique having good signal to noise ratio. Hence Fast ICA technique is more efficient technique than other conventional techniques including LMS technique. The expected waveform of Fetal ECG is obtained almost exactly with good SNR value. Usage of single channel data is one limitation of all the other techniques, where I used 6 channel data. For more number of channels the result will be better.

FUTURE SCOPE

In this paper, Fast ICA Analysis and Adaptive filtering techniques are separately used and six channel data is used for the implementation.

Hence the future work can involve:

- Exploring other filter methods to obtain better results.
- Programming techniques can be used to compare Fast ICA and LMS algorithms.
- Use of Power spectral density of each signal to compare the two algorithms. .

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