PRINT: ISSN 0973-5070 ONLINE: 2456-6772
Ethno Med, 8(3): 251-258 (2014)
DOI: 10.31901/24566322.2014/08.03.07

Extracting Fetal Electro Cardiogram Signal to Monitor Congenital Heart Problems Using Framelet

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KEYWORDS Electrocardiogram. Maternal. Abdominal. Framelet Transform. Mean Square Error

ABSTRACT Gynecologists are interested in measuring the Fetal Electro Cardiogram (FECG) signal since it provides reliable information about the fetal status, the detection of abnormalities and to detect whether the fetus is alive or dead. Non-invasive technique is preferred for this to avoid the breaking up of the membrane which protects the child. The problems associated with the non-invasive interaction are mainly due to the low power of FECG signal which is contaminated by various sources of interference. The proper checking of fetal heart and the prior recognition of cardiac problems make heart specialist to recommend proper medication in that moment or to take the essential safety measures during delivery or after labor. The enduring look of mother's ECG signal in which the amplitude is 5-20 times more than that of FECG is considered to be a maddening one. A new method for filtering FECG from Abdominal ECG (AECG) is proposed. In the midst of the several noises that taint FECG, the noise which is needed to be eliminated is the mother's noise generated in the abdomen. The current work aims to get rid of the mother's ECG signal (MECG) and to extract a perfect FECG. The performance of the proposed method is evaluated by Mean Square Error (MSE) and Peak Signal to noise ratio (PSNR). The result shows that the Framelet Transform (FT) produces minimum MSE and high Peak Signal to Noise Ratio (PSNR) than Discrete Wavelet Transform (DWT).

INTRODUCTION

FECG signal extraction is an interesting but a difficult problem in the field of bio-medical signal processing since the FECG signal picked up from the mother's abdomen is mixed with MECG and other contaminated noises. The decrease in fetal movement is diagnosed only by examining the absence of cardiac activity in fetal heart which may lead to fetal death.

Non-invasive method provides less information about the fetal condition compared to invasive method which is more risky for mother's health. With the limited number of information, doctors find it difficult to diagnose the heart problems such as cardiac hypertrophy, arrhythmias and Congenital Heart Defects (CHD). The extracted FECG contains information about the health status of the fetus, fetal well-being, fetal positioning, multiple pregnancies and fetal maturity.

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Finite Impulse Response (FIR) neural network is proposed by Sanyal et al. (2012) for FECG extraction. Novel methodology is presented for selecting the optimal topology. The outcomes of this method demonstrate that FIR network is a reliable method for fetal electrocardiogram. Khamene et al. (2000) proposed Adaptive Neuro Fuzzy Interference Systems (ANFIS) for FECG removal from the two ECG signals recorded at the thoracic and mother's abdomen. The thoracic ECG is considered to be nearly maternal electro cardiogram (MECG) while the ECG signal taken from the abdomen is considered to be complex as it contains both mother and fetal ECG signals. The mother's constituent in the abdominal ECG signal is a nonlinearly distorted version of the MECG. ANFIS system is used to identify this nonlinear association and to line up the MECG signal with the mother's component in the abdominal ECG signal. The result is validated on both real and synthetic ECG signals. Results show that the technique is capable of extracting the FECG even when it is totally embedded within the maternal QRS complex.

FECG extraction by blind source separation with the reference signal (BSSR) is proposed by Saritha et al. (2008) to cancel the maternal ECG component by subtracting the linear combination of reciprocally orthogonal projections of the heart vector. The BSSR is a fixed-point algorithm, the Lagrange function of which includes the higher order cross-correlation between the filtered signal and the reference signal as the cost term rather than a limitation. The extracted fetal ECG is same as that of the magneto-cardiogram, which proves the system more applicable. ECG signal analysis using wavelet transform Hadeel et al. (2010) is proposed. Further, the coefficients of wavelets at higher scales are removed in order to remove noise from the ECG signal. The detected QRS complexes were used to ûnd the peaks of the and deviation of waves P and T. Image de-noising using Framelet Transform method is proposed by Kumar et al. (2013) in which one and two dimensional framelet transform was computed. The processing time for decomposition of image is reduced by this method and thereby the qualities of the reconstructed images are improved. Some of the above denoising schemes are tested on Peppers image to find its effect on de-noising application.

Comparative analysis of FECG extraction techniques using two adaptive filters based on recursive least square (RLS) and normalized least mean square (NLMS) is proposed by Sato et al. (2007) in which the reference and primary signals are fed simultaneously to the inputs of the RLS and NLMS adaptive filters to extract the fetal signal. Experimental results clearly show that adaptive filtering using RLS algorithm performs better in extracting the fetal ECG signal. The combination of adaptive filter and GA is proposed by Amrani et al. (2006) where Genetic Algorithm (GA) is used whenever the adaptive filter reaches a local maximum.

Gokhale (2012) proposed DWT technique to remove 50Hz power line interference (PLI). Many ECG signals with PLI from MIT/BIH arrhythmia database are used. De-noised ECG signal is compared with original signal to calculate MSE and SNR. MSE and SNR parameters were calculated and compared with IIR method and wavelet transform method. Remi and Jebila (2014) proposed Kalman filter for FECG and MECG extraction and also estimate maternal blood pressure. Here, the results are not justified through mathematical evaluation. A new method of extracting FECG using Wavelet Transform and Genetic Algorithm proposed by Sulochana and Vidhya (2012) uses an architecture which is a combination of Wavelet transform, adaptive filter and Genetic Algorithm (GA). The hybrid combination of wavelet transform and the GA provide the expected result. Umamaheswari and Kumar (2014) proposed adaptive LMS algorithm for FECG extraction. Framelet Transform proposed by Anandan and Murugesan (2012) to eliminate baseline drift from ECG signal by applying a time-frequency transformation (TFT) technique. This is based on smooth wavelet tight frame with vanishing moments. This baseline drift moves the iso-electric line of the ECG which in turn shifts the ST segment of the original signal. This may be misinterpreted as cardiac ischemia or myocardial infarction. Cherian et al. (2014) proposed GA based FIR is more effective when multi channel signals are considered for FECG extraction.

METHODOLOGY

The main contents of proposed system for FECG signal extraction from MECG signal is based upon Framelet technology. In the following section, theoretical approaches such as Framelet concepts, Framelet Transforms and algorithm for FECG extraction using Framelet transform is discussed.

Framelets

Short-time Fourier Transforms (STFT) and Discrete Wavelet Transform (DWT) method are applied in pre-processing non-stationary signals. This study investigates the performance of Framelets in extracting FECG from MECG by decomposing wavelets into frames. Hence these wavelet frames are called Framelets. Frames present superfluous representations of signals. This redundancy helps to develop frame expansion as a tool for FECG signal recovery. The frame, which is useful for signal processing, is the class of frames generated by oversampled perfect reconstruction filter banks (OPRFB). In general, the frame transforms of ECG signals provided by filter bank can be interpreted as joint source-channel encoding for lossy channels, which is pliant to quantization noise. The three-channel non-decimated filter banks produce the frames.

Three-channel OPRFBs Wavelet frames (framelets) generate wavelet frames with the down sampling factor of 2. Such frames provide a minimal redundancy. The frames merge high computational competence of the wavelet pyramid scheme with the power and suppleness of superfluous representations. The framelets generating from the filter banks possess a combination of properties that are valuable for signal and image processing: symmetry, interpolation, time-domain localization, flat spectra and any number of vanishing moments. This method is very simple and less complex in decomposing and reconstructing the designed frames whish will lead to efficient recovery of fetal ECG. These properties have good error recovery capabilities.

Concept of Framelets

For most of the signals, the low-frequency content carries the information. It gives the signal its uniqueness. The high-frequency content gives imparts flavor or fine distinction. Here in this study, more focus is given to remove MECG which has low frequency. In framelet analysis, the signal which has to be de-noised is first down sampled by a factor of 2 before subjecting to various levels of decomposition. This process of decomposition is brought about by the filter banks. The filter banks has low pass filter, band pass filter, High pass filter and hence the signal is decomposed according to its frequency. After each level of decomposition, the frames are subjected to a particular family of wavelets. The de-noised signal is then again composed by using a set of filters called synthesis filter banks. The signal obtained has to be interpolated back by a factor of 2 to attain the same number of samples which were before de-noising.

Framelet Transform

For analysing and processing most of the real signals and images, Wavelet Transform is an essential tool, but it undergoes three major disadvantages. They are Shift- sensitivity, Poor directionality and Lack of phase information. These problems keep some limitations for certain signal and image processing applications. To overcome the above mentioned disadvantages, The Framelet Transform (FT) is proposed to get rid of the above mentioned problems.

A mathematical tool used to analyze many types of signals is the Framelet transform. It is also useful in other applications such as data compression, adaptive equalizer and trans-multiplexer. Even though, Framelet transform is similar to wavelets but it has many differences. More than two high frequency filter banks are present in Framelets so that more sub-bands are produced in decomposition. Time frequency localization is easily achieved using framelets in signal processing. There is idleness between the Framelet sub-bands that is coefficient change in one band can be supported by other sub band coefficients. The coefficient in one sub-band has association with coefficients in the other sub-band after Framelet decomposition. Noise reduction in original image is achieved by adjusting coefficient in one band by the related coefficients of the other. Decomposition of a signal into shifted and scaled versions of a wavelet is done by Framelet analysis.

The most important property of Framelet analysis is perfect reconstruction, which is the process of reconstructing a signal into its original form without much loss of useful data. Set rules are not applicable to select the mother wavelet used for analysis. The choice depends on the properties of the mother wavelet, the properties of the signal to be examined, and the requirements of the analysis. Let square integrable space or a Hilbert's space H is assumed as L2. Then the vectors finite family $ø = \{ø_1, ø_2, ø_3, ... ø_N\}$,e H may be defined in equation 3.1 as a tight frame of H if

$$\Sigma^{N}_{i=1} \Sigma_{j,k} |< f, \psi^{i}_{jk} >|^2 = ||f||^2 \ \forall f \ \varepsilon \ \mathbb{H} \qquad 3.1$$

where, $ø_i$ is normalized by the constant in order to obtain a frame bound equal to 1. As a result of the above, framelets are applied via multi-resolution analysis (MRA) in which scaling function and the wavelets are explained by a two scale relation as:

$$\varphi^{(t)} = \sqrt{2} \sum_{k} h_o (k) \ \varphi (2_t - k) \qquad 3.2$$

$$\varphi^{m(t)} = \sqrt{2} \sum_{k} h_m (k) \ \varphi (2_t - k); \ m \ \varepsilon \ \mathbb{Z} \qquad 3.3$$

The sequence $h_0 = h_0(k)$ is the cover of ö. A solution of ö from equation:

$$\{\varphi_{jk} = M^{j/2} \ \varphi \ M^{j} - k); \ j, k \ \varepsilon \mathbb{Z} \} \qquad 3.3$$

is called a distribution function associated with the mask.

From equation (3.4) it is known that for a given j, the whole family of { ö $_{jk}$} can be produced by changing ö by k and dilate it by M_j. For this condition, the scaling function ö = ö $_{(0,0)}$ is also known as the 'father' wavelet. The growing 2 × 2 matrix is an dilation matrix M. All the elements present in M are integers, |det M| = 2 and the values greater than 1 are modulo of the Eigen values of M. It is also explained in other way as a unique tempered allocation of ö which is re-finable, that means it is closely related, with respect to $h_0(k)$ and is present in H that has the potential of producing an MRA. Two wavelets are taken into account in this case. They are obtained by substituting m = 1 and 2 in equation (3.3).

Description of the Filter Bank

For m =1, 2 it is observed from equations (3.2) and (3.3) that the array generally has a three-channel filter bank of which $h_0(k)$ is a low pass filter, $h_1(k)$ is a band pass filter while $h_2(k)$ is a high pass filter $\forall k \varepsilon Z$. These three filters collectively produce the forward transform analysis filter bank and each filter is down-sampled by 2. For the inverse transform, the synthesis filter bank is derived by taking transpose of the analysis filter bank. This shows that the synthesis filters are the time-reversed versions of the analysis filters. The wavelet tight frame is formed by two symmetric wavelets $\psi_1(t)$ and $\psi_2(t)$ with frame bound given as 0.5 $-||h_j||^2$ with j = 1, 2. The vanishing moments of wavelet functions $\psi_1(t)$ has two and $\psi_2(t)$ has three.

Framelet Features

Framelet transformation is a transform which does not impose one to one correspondence between signals and its transform coefficients. Framelet transform is known as double-density discrete wavelets transform (DDWT). This transform has two times more wavelet coefficients than DWT coefficients. Filter banks have analysis and synthesis filters and are stored as the cell array.

Algorithm for FECG Extraction Using Framelet Transform (FT)

Step 1: Simulate the thoracic and abdominal signals with the help of standard data available.

Step 2: ECG signal is passed through series of 'analysis filter banks' (Low pass, high pass and band pass) for decomposition. Every increase in level gives a greater resolution and can be de-noised with greater efficiency. In this step, the Framelet coefficients are obtained. Signal decomposition through filter banks occur as shown in Figure 1.

Step 3: Apply Soft threshold to the Framelet coefficients and de-noise it.

Step 4: Apply 'Synthesis Filter Banks' to bring together the different segments having different frequency.

Step 5: Apply various adaptive filters to the de-noised signals obtained.

Step 6: Apply Framelet transform and soft threshold to extract the de-noised FECG signal.

Framelet Transform technique is applied to simulated noisy AECG signal and after soft thresholding and inverse FT, the output waveform still contains noise along with original signal. Similarly, the FT is applied to simulated noisy thoracic signal and after soft thresholding and inverse FT, the output has reference noise which has to be subtracted from AECG signal. Then to the extracted FECG signal, FT is applied to refine the FECG signal and it is shown as block diagram in Figure 2.

RESULTS

To evaluate the performance of the proposed system in extracting the FECG signal from the MECG signals, experiments were conducted on the simulated AECG and TECG signals. Noisy AECG signal simulated with sampling rate of 4000 Hz and de-noised using FT is shown in Figure 3. Noisy TECG signal simulated with sampling rate of 4000Hz and de-noised using FT is shown in Figure 4. The required FECG signal is extracted by subtracting TECG from AECG and the output is again passed through FT to get the noise free FECG signal as shown in Figure 5.

Numerical evaluation is done by calculating the mean square error between the de-noised FECG signal and the original FECG signal. The performance of the proposed FT method is compared with DWT. Experimental results proved that the Framelet transforms produce best results, as the PSNR value of FT is higher than DWT. Soft threshold is preferred for FECG extraction since it produces less MSE and high PSNR. Experiments done with DWT and FT for various adaptive algorithms such as Least Mean Square (LMS), Recursive Least Square (RLS), Frequency Domain Filter, Lattice based FIR filter and the results are tabulated in Table. 1. DWT used here is Coiflet and Daubechies (Db 6). The MSE value of FT is very less compared to DWT.

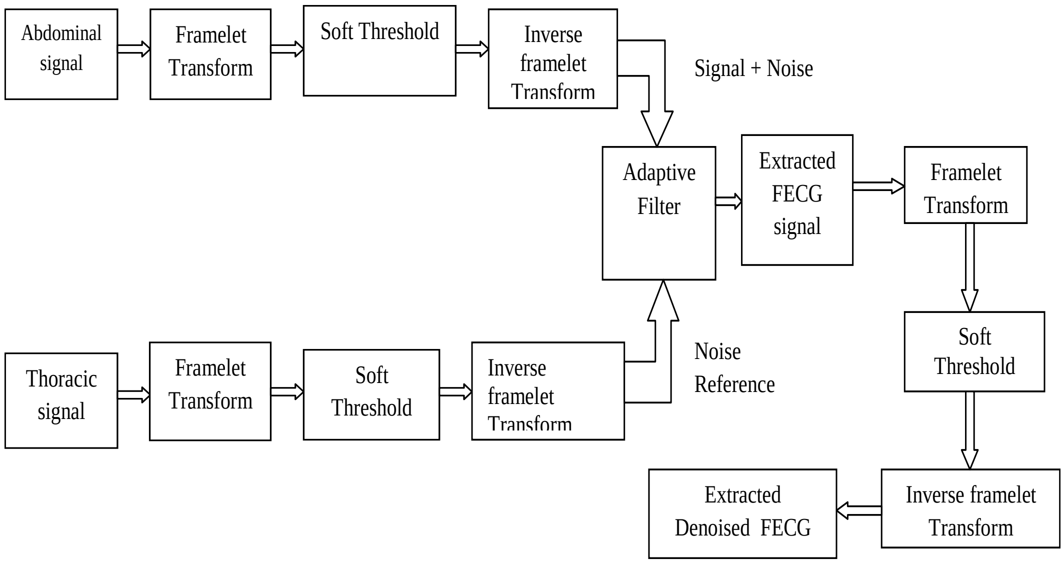

Fig. 1. Signal decomposition through filter banks

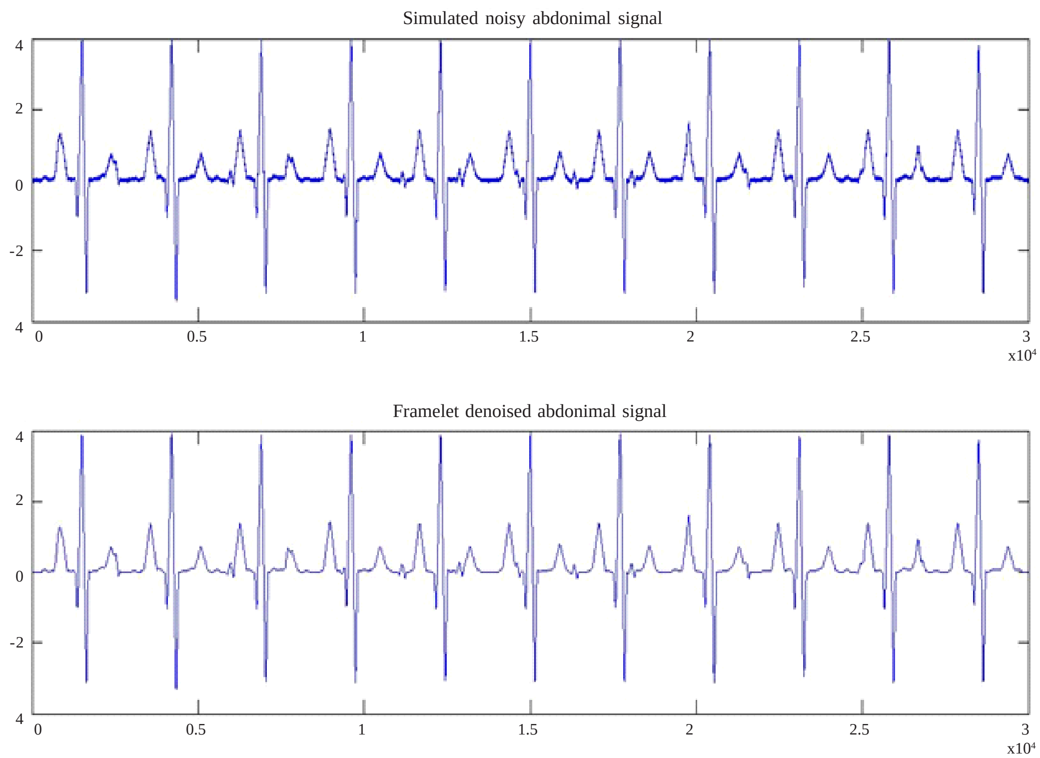

Fig. 2. Block diagram of the proposed FECG extraction technique

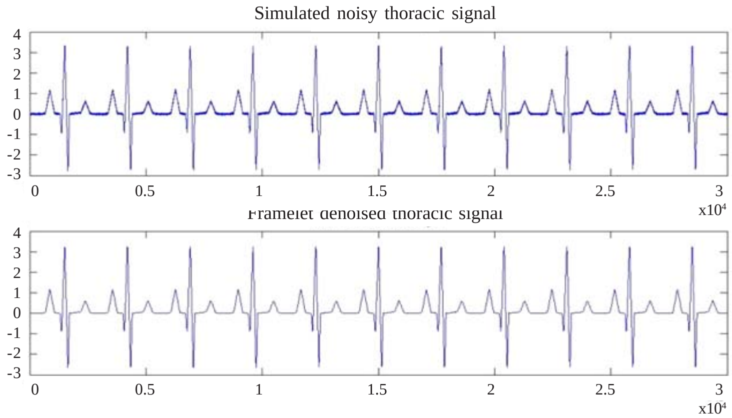

Fig. 3. Abdominal ECG signal

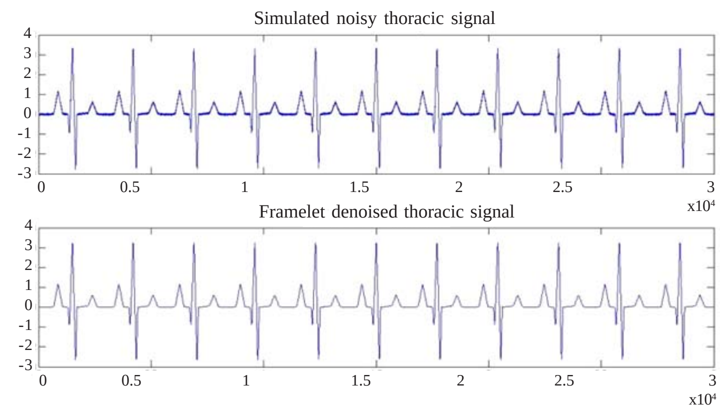

Fig. 4. Thoracic ECG signal

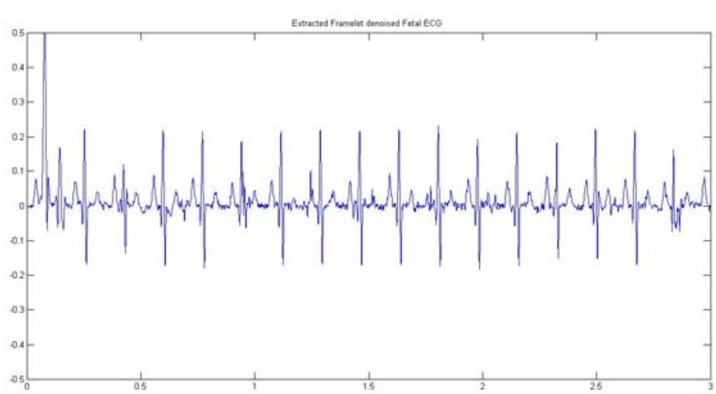

Fig. 5. Extracted fetal ECG

Table 1: MSE and PSNR values for various algorithms in adaptive filtering to extract FECG

Algorithms	*COIFLETS*		*DB6*		*Framelets*	
	MSE	*PSNR*	*MSE*	*PSNR*	*MSE*	*PSNR*
			Least Mean Square			
lms	0.0028	161.7828	0.0028	161.7828	0.0014	171.42
nlms	0.4738	110.5588	0.4737	110.5588	0.0019	169.3
blms	0.0029	161.3929	0.0029	161.3929	0.0014	171.47
dlms	0.0028	161.6964	0.0028	161.6964	0.0014	171.45
blmsfft	0.0029	161.3924	0.0029	161.3929	0.0014	171.50
filtxlms	0.0081	151.1938	0.0081	151.1938	0.0015	171.31
sd	0.0024	163.3156	0.0024	163.3156	0.0013	171.54
se	0.0017	167.0975	0.0017	167.0975	0.0010	171.84
ss	0.0076	151.9491	0.0073	151.9491	0.0015	171.37
			Recursive Least Square			
qrdrls	0.0024	163.2216	0.0025	163.2216	0.0013	171.54
swftf	0.0021	164.5505	0.0021	164.5508	0.0012	171.62
ap	0.0450	134.0989	0.0450	134.0091	0.0016	171.00
apru	0.0352	136.5695	0.0352	136.5703	0.0016	171.21
bap	0.0921	126.9375	0.0921	126.9376	0.0017	169.91
			FIR (Frequency Domain)			
fdaf	0.2660	116.3326	0.2660	116.3337	0.0018	169.4
pbfdaf	0.8799	104.3691	0.8786	104.3840	0.0019	169.00
pbufdaf	0.1901	119.6930	0.1906	119.6632	0.0018	169.2
tdafdct	0.0095	149.6701	0.0095	149.6701	0.0016	171.2
fdaf	0.2660	116.3326	0.2660	116.3337	0.0018	169.4
			Lattice Basd FIR Filter			
gal	0.0328	137.2583	0.0328	137.2583	0.0017	171.04
lsl	0.0024	163.2216	0.0025	163.1354	0.0013	171.54
qrdlsl	0.0024	163.2216	0.0025	163.1354	0.0013	171.54

It is evident from the simulated result tabulated in Table1 that FT minimizes the error rate and improves the PSNR much better than DWT.

DISCUSSION

FECG signal extraction from MECG gives more information about the health of the fetus. If any Cardiac abnormalities are found at the earlier stages, it helps the doctor to give medication to avoid congenital heart problems thereby fetal life can be saved. Various methods already available for FECG separation produces more MSE and less PSNR value which indicates that the exact FECG separation is not possible. Recently published papers have not produced mathematical evaluation to assess the accuracy and the outputs are analyzed only by viewing the extracted signal. PSNR value obtained using FT is 171 whereas for DWT, PSNR value is 160. The proposed system improves PSNR value compared to already available techniques. It is believed that this proposed method can become a diagnostic tool for the treatment of fetal arrhythmias.

CONCLUSION

In the present study, separation of FECG signal from MECG signal using FT is proposed. As FT produces better separation than DWT, it produces an excellent result in the FECG signal extraction. Actual output waveform is compared with the original signal and found that MSE value of proposed technique is low compared to DWT. Hence the proposed technique might be a life saving tool for the fetus as it gives the physiological condition of the fetus.

RECOMMENDATIONS

This work is highly recommended for the society to extract FECG signal from pregnant woman in a non-invasive manner which will prevent fetal death due to congenital heart problems.

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