International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-8 Issue-4, April 2019

Fetal Electrocardiogram Signal Enhancement Using Savitzky-Golay Filter

Jayprakash Nayak, Om Prakash Yadav

Abstract— Fetal electrocardiogram (FECG) records electrical activity of the fetal heart and is mainly referred for fetus heart condition. These signals are always contaminated with noises of various kinds which alter their characteristics and thus it may lead to wrong interpretation and diagnosis. Thus these signals need to be clean for correct diagnosis. In this paper, an attempt to reduce noise from FECG signals of physionet database through Savitzky-Golay has been presented. The proposed method is accessed through standard tools like Mean Absolute Error (MAE), Percentage RMS Difference (PRD), Signal to Noise Ratio (SNR) and Cross Correlation (CC). The results obtained are found to be diagnostically acceptable.

Keywords—FECG, AECG, MECG, Savitzky-Golay filter, MAE, PRD, SNR, CC.

I. INTRODUCTION

The Fetal electrocardiography (FECG) is a biomedical procedure to determine the potentials generated electrical activity of fetus heart during pregnancy and at childbirth. FECG's are mainly referred for issues related to fetus heart are mainly required for diagnosis cardiac defects in fetus heart [1]. Every year, around one out of 125 infants are brought into the world with a couple of state of inborn heart absconds, i.e., congenial heart defects (CHD) [2]. The disfigurement might be slight to the point that the youngster appears sound for various quite a while after birth, or so extraordinary that its life is in brisk danger. CHDs begin in beginning periods of pregnancy when the heart is molding and they can impact any of the parts or limits of the heart [3] FECG flag contains conceivably exact data that could help clinicians in settling on progressively suitable and auspicious choices amid pregnancy and labor. The FECG is especially identified with the grown-up ECG, containing similar essential waveforms including the P wave, the QRS complex, and the T wave. P wave is created because of electrical potential produced by atrial depolarization. The magnitude of P wave is normally low. QRS Complex is generated when the ventricles depolarize before contraction or when the depolarization wave spreads through the ventricle. Accordingly, both the P wave and segments of QRS complex are depolarized waves.

Manuscript published on 30 June 2019.
***** Correspondence Author (s)
Jayprakash Nayak*, Department of Electronics & Telecommunication Engineering Chhatrapati Shivaji Institute of Technology, Durg (C.G.), India, 491001
Om Prakash Yadav, Department of Electronics & Telecommunication Engineering Chhatrapati Shivaji Institute of Technology, Durg (C.G.), India, 491001

Q wave is introductory negative diversion coming about because of ventricular depolarization. R wave is first positive redirection coming about because of ventricular depolarization. S wave is first negative redirection of the ventricular depolarization that pursues the primary positive avoidance. T wave is because of ventricular repolarization [4]. Though there are similarities between the electrical properties of fetal and adult, the R-R interval and morphology are different. The FHR (fetus heart rate) is almost twice as fast as an adult heartbeat and it changes in different stages of fetal cardiac development [5]. Broadly, FECGs can be obtained in two ways. The first way is invasive (direct method) and other one is non-invasive method which is also known as indirect method. In invasive method, FECG is directly obtained through the electrodes placed inside the uterus of the mother on the scalp of the fetus. The advantage of the invasive method is that it provides clearer and most consistent FECG. However, it may provide harm (mark/cut on baby's head) and is only obtained during delivery. Non-invasive monitoring is done through the skin sensitive electrodes placed on mother's abdomen through conducting jelly. The advantage of this procedure is that the fetus does not receive any harmful radiations directly and hence the procedure can be done for longer duration. FECG getting from non-invasive monitoring is also called AECG (Abdominal ECG) which is a combination of FECG, MECG (Maternal ECG) and a few noises. MECG are high amplitude signal which cover the FECG signal. So, MECG are the main sources of disturbance to FECG signals and even these disturbances make FECG unreadable for accurate interpretation. Figure 1 shows one cycle of FECG signal.

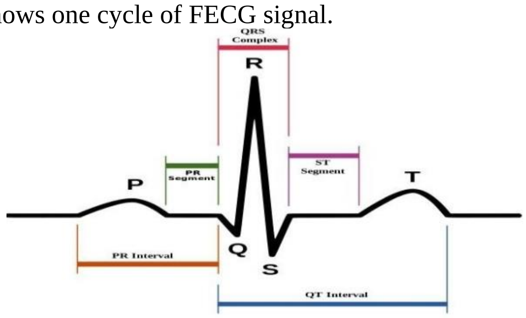

Figure 1. A Normal FECG signal along with component waves

II. NOISES IN FECG SIGNALS

The morphology of the FECG depends upon location of the electrodes, the gestational age, and the fetus position. The majority of the previously mentioned limitations make the FECG discovery and extraction a troublesome procedure.

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication (BEIESP)

In this way, it is imperative to comprehend the attributes of commotions present in FECG. Electrical commotion influencing FECG signs can be ordered into the accompanying kinds:

A. Power line interference (PLI)

Electrical cable obstruction comprises of 50 Hz pickup and sounds. By utilizing low clamor electronic intensifiers with high normal mode dismissal proportion, the impact of 50Hz electrical cable obstruction and the electronic irregular commotion can be diminished [6].

B. MECG signal

Maternal ECG (MECG) is the most overwhelming meddling sign in the abdominal signal. The recurrence range of this commotion covers that of the FECG and along these lines separating alone isn't adequate to accomplish sufficient clamor decrease [7].

C. Maternal Muscle noise

Muscle clamor is because of maternal development, frequently because of development of legs and muscular strength and might be gotten from the reference cushion on the maternal thigh. Electromyography (EMG) action in the muscles of the midriff and uterus is the wellspring of this sort of commotion. In some cases, it is hard to recognize the EMG motion in the stomach flag. EMG commotion can be decreased however not really dispensed with the utilization of established low pass separating procedures [8].

D. Electrode contact noise

This clamor is brought about by loss of contact between the skin and cathode, which likewise impacts the estimation of the signal [9].

E. *Motion artifacts*

Motion artifact results in abnormalities in the recorded signal and it may be due to electrode interface and electrode cable. This can be reduced to greater extent by proper design of the electronic circuitry and setup [10].

III. EXISTING LITERATURE FOR REDUCTION OF NOISES FROM FECG SIGNALS

Maniknandan et al. extracted FECG from MECG of physionet database using adaptive noise cancellation technique through least mean square (LMS) algorithm. Two sets of FECG, i.e., AECG and MECG from mothers chest have been utilized. The calculation is actualized so that it initially distinguishes all picks with reference edge (5% above and beneath) which can be physically balanced. The edge is picked with the goal that to be missed and wrong pinnacle ought no pinnacle to point to not be chosen [11]. Vasudev and Dessai extracted FECG from AECG using MATLAB. The system identifies the maternal QRS complex through wavelet transform. Notch filter with 50 Hz frequency is used to remove PLI noise and Butterworth bandpass filter to reduce high frequency noises. After denoising the FECG signal, peak detection algorithm is then applied to detect fetal R peak in order to calculate the RR interval. This RR interval is used to calculate the fetal heart rate (FHR) [12]. Ungureanu et al. worked on suppression of PLI component and its harmonics from the FECG signal. They analyzed six different principles and evaluated the result on simulated data based on five quantitative performance indices [13]. Emuoyibofarhe et al. designed adaptive Neuro fuzzy inference systems (ANFIS) for the reduction of MECG from AECG. In this paper, MECG and FECG signals were created in MATLAB and then these signals are added to produce AECG. For the fetal heartbeat data to be recuperated from the obstruction (maternal heartbeat) data, a reference data, which is a spotless adaptation of the first maternal heartbeat data, was presented in the framework [14]. Rastogi and Mehra [15] used Savitzky-Golay algorithm to suppress baseline wander noise. Total 20 non-invasive ECG samples, sampled at 1 kHz with 16 bit resolution were utilized to evaluate the performance of the proposed method. A commotion of 0.2 Hz recurrence is added to these signals to make them uproarious ECG signals. At that point Savitzky-Golay FIR smoothing channel having polynomial request of 0 and casing size 15 is connected. At that point a smooth capacity is connected on separated signal. Niknazar et al. connected Extended State Kalman sifting dependent on single-channel to ECG signals. They perform extraction of FECG from one blend of MECG and FECG and FECG was analyzed concurring the commotion level, plentifulness proportion and pulse proportion parameters [16]. Prasanth et al. [17] took a shot at expulsion of clamor and ancient rarities from FECG signal. The proposed technique utilizes versatile commotion undoing and computerized channels for FECG extraction. From the recreation results they inferred that FECG signs can be separated from AECG signals utilizing LMS calculation by evolving tap-weight vector. Fetal pulse signals are extricated from the pinnacles of R-R interim. Zhou et al. connected Independent Component Analysis (ICA) and Wavelet Transform to get FECG from the genuine examined chronicles. Wavelet detrending and wavelet denoising were utilized as pre-preparing stages to dispense with different sorts of clamor and, Fast ICA calculation was utilized to gauge the FECG signals [18]. Awal et al. built up a way to deal with smoothing the ECG signal utilizing S-Golay channel. They talked about the impact of the variety of polynomial degree and edge measure. For denoising ECG motions by utilizing S-Golay channel, PRD and SNR are utilized as the execution assessing factor. The test results demonstrate the determination technique for polynomial degree and edge measure [19]. Schafer provided details on S-Golay filters and discussed about least-squares smoothing of signals, properties of S-Golay filters and design of S-Golay filters [20]. Reza Sameni et al. had given the audit of fetal ECG signal processing. They talked about on physiology of fetal heart like fetal heart improvement, life structures of fetal heart, electrical action of fetal heart and thought about different sifting [21]. Kotas consolidated autonomous part examination (ICA) and projective sifting to extricate the FECG [22]. Assaleh et al. separated the FECG motion from ECG recorded at the thoracic and stomach territories of the mother's skin and distinguished the nonlinear connection between maternal segments in stomach ECG and thoracic MECG. They played out that procedure on both genuine and engineered ECG signals [8]. Daniel Graupe et al. [23] proposed blind-adaptive filtering approach for extracting FECG from MECG early stages of pregnancy. The crude ECG was recorded from 3 regular ECG anode channels recorded on the midriff of pregnant mother at the 24th development week. Yadav and Ray proposed total variation approach to filter out ECG signals of MIT-BIH database [24].

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication (BEIESP)

Chebyshev polynomials were also utilized for reduction of noises present in ECG signals in [25].

IV. METHODOLOGY

A. Savitzky Golay filter

Savitzky golay (S-Golay) smoothing channel was presented by Abraham Savitzky and Marcel J. E. Golay in 1964. S-Golay channel is a low pass advanced channel that can be connected to a lot of computerized information focuses to smooth the information and in this way expanding the flag to clamor proportion without bargaining the nature of the flag. To decrease clamors from time-changing non-stationary FECG signals while protecting transient impacts, we can apply the proposed S-Golay channel. The denoised sample points $(y_k)_s$ for n noisy sample $y = 1, \ldots, n$ points by S-Golay filters is obtained by the following equation:

$$(y_k)_s = \frac{\sum_{i=1}^{n} A_i y_{k+1}}{\sum_{i=1}^{n} A_i}$$

Where A_i is a set of integers acting as weighting coefficients for denoising.

B. Noise Generation and Addition

The data used for examination has been taken from physionet database. We have considered two arrangements of data; first set contains motion from moms belly comprising of fetal ECG, maternal ECG and clamor though second set contains maternal ECG taken from the mother's chest. The available data is in ".mat" file format with the different frequency range. We have taken abdominal and direct fetal ECG data of standard data format with 1 KHz sampling rate. Duration of each signal is 10 second with 1Hz to 150Hz bandwidth [26]. All the simulations are done in Matlab environment. From these signals FECG signal is extracted and then AWGN noise of 30 dB is added to these signals for further analysis.

S-Golay filter with Polynomial order k = 6 and frame length f = 31 parameter is then applied to these signals to reduce noises.

V. PERFORMANCE PARAMETERS

The proposed denoising model is assessed through following parameters:

A. Mean Absolute Error (MAE)

MAE evaluates the average errors, without considering their direction. It's the normal over the test of the outright contrasts among forecast and real perception where every single individual distinction have rise to weight.

$$\mathrm{MAE} = \frac{1}{n}\sum_{j=1}^{n} |y_j - \hat{y}_j|$$

B. Percentage Root Mean Square Difference (PRD)

Percentage Mean Square Difference is a proportion of blunder misfortune. This measure assesses the mutilation between the actual and the recreated signal.

$$\mathrm{PRD} = \left(\frac{\text{Reconstructed noise energy}}{\text{Original signal energy}}\right)^{\frac{1}{2}} \times 100$$

C. Signal to Noise Ratio (SNR)

SNR is the power proportion between actual signal and noise and is calculated in logarithmic scale. It is given as:-

$$\mathrm{SNR} = 10\log_{10}\left(\frac{E_{signal}}{E_{noise}}\right)^2$$

$$\mathrm{SNR} = 20\log_{10}\left(\frac{E_{signal}}{E_{noise}}\right)$$

where:-

E_{signal}: Root mean square of the actual signal.

E_{noise}: Root mean square of the noise.

D. Cross Correlation (CC)

A connection coefficient (r) is a coefficient that delineates a quantitative proportion of some kind of relationship and reliance, which means measurable connections between at least two irregular factors or watched information esteems. Cross connection is a standard strategy for evaluating how much two arrangement are corresponded. Consider two series x(i) and y(i) where i = 0, 1, 2 ... N-1. The cross correlation r at delay d is defined as:

$$\mathbf{r} = \frac{\sum_i[(x(i) - mx) * (y(i-d) - my)]}{\sqrt{\sum_i (x(i) - mx)^2}\ \sqrt{\sum_i (y(i-d) - my)^2}}$$

Where 'mx' and 'my' are the means.

V. RESULTS

We have utilized the physionet database to test the execution of the S-Golay channel on FECG signals acquired from multichannel accounts from 5 distinct ladies in labor, somewhere in the range of 38 and 41 weeks of gestation. The FECG information are tested at 1 KHz and the goals of each example is 16 bits/tests. Table 1-5 shows the results obtained the 5 sets of FECG signals.

Table 1: Performance parameters for the signal: r01_edfm

S. No.	Performance Parameter	Value
1	MAE	99.6857
2	PRD	4.2239
3	SNR	27.4857
4	CC	0.9991

Table 2: Performance parameters for the signal: r04_edfm

S. No.	Performance Parameter	Value
1	MAE	56.7047
2	PRD	5.4895
3	SNR	25.2093
4	CC	0.9985

Table 3: Performance parameters for the signal: r07_edfm

S. No.	Performance Parameter	Value
1	MAE	58.9298
2	PRD	3.4330
3	SNR	29.2865
4	CC	0.9994

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication (BEIESP)

Table 4: Performance parameters for the signal: r08_edfm

S. No.	Performance Parameter	Value
1	MAE	108.3224
2	PRD	6.1760
3	SNR	24.1859
4	CC	0.9980

Table 5: Performance parameters for the signal: r10_edfm

S. No.	Performance Parameter	Value
1	MAE	160.1011
2	PRD	2.5809
3	SNR	31.7645
4	CC	0.9997m

From the Tables 1-5, we can observe that the maximum value MAE is 160 for the record r10_edfm which can be considered to be neglible for such type signals. PRDs for faithful reconstruction should be less than 10 and in this paper, all PRDs are within the range. SNR of the reconstructed is even more than 20 for all signals which indicates that the signal strength is preserved over noise. The structural similarity is also retained by all signals as CC is almost near to 1. Thus, the proposed model is medically acceptable.

Figures 2 shows the component waves i.e., FECG, MECG and Abdomen waves of r10_edfm signal of MIT –BIH database.

Figure 3 represents FECG signals, AWGN added FECG signal and S-Golay filtered FECG signal.

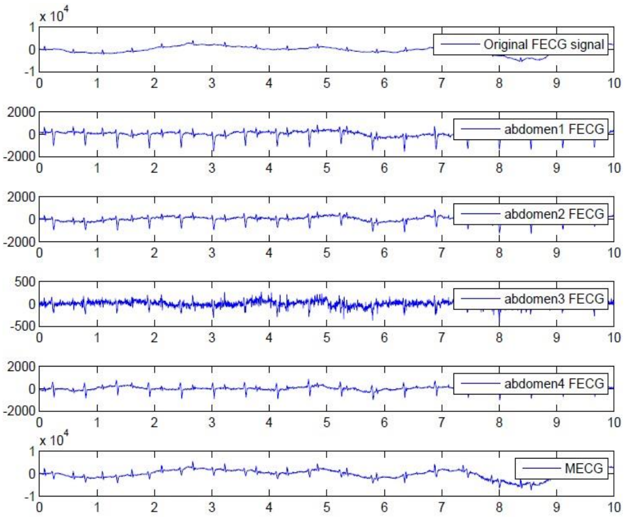

Figure 2: Original FECG signal and abdominal FECG from different channel of r10_edfm signal.

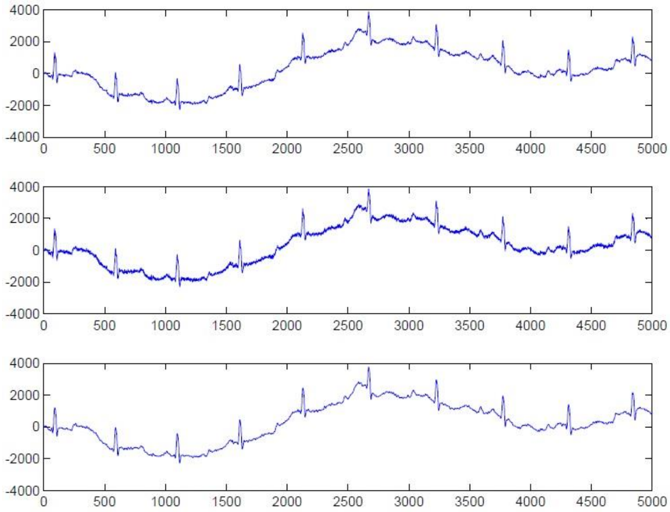

Figure 3: Direct FECG signal, FECG signal with AWGN, filtered FECG signal.

VI. CONCLUSION

Heart sicknesses are ascending on the planet these days and it is being the essential reason of death and the FECG is principle huge instrument to analyze the heart related issues of hatchling. These signs are nonetheless, adulterated by clamors which impacts the determination and yields inappropriate information. In this paper, Physionet Database for abdominal and direct fetal ECG has been used. These signals are then made noisy by adding additional noise of predefined magnitude. Then these signals are passed through the S-Golay filter. The performance of the proposed method is assessed with standard FECG denoising parameter and is found to be within diagnostic limits.

REFFERENCES

1. Khaled Assaleh, "Extraction of Fetal Electrocardiogram Using Adaptive Neuro-Fuzzy Inference Systems," *IEEE Transactions On Biomedical Engineering*, vol. 54, no. 1, pp. 59-68, January 2007.
2. Reza Sameni and Gari D. Clifford, "A Review of Fetal ECG Signal Processing; Issues And Promising Directions," *The Open Pacing, Electrophysiology & Therapy Journal*, vol. 3, pp. 1-30, 2010.
3. Boaz Weisz, Helen V. Firth and Lyn S. Chitty Eva Pajkr, "Fetal Cardiac Anomalies and Genetic Syndromes," *Prenatal Diagnosis*, vol. 24, no. 13, pp. 1104-1115, December 2004.
4. Santosh kr. Dubey and Om Prakash Yadav, "Denoising and Compression of ECG Signal using Wavelet Packet," *International Journal of Trend in Research and Development*, vol. 4, no. 2, pp. 273-277, Mar-Apr 2017.
5. Lisa K., and David J. Sahn Hornberger, "Heart," *Rhythm Abnormalities of the Fetus*, vol. 93(10), pp. 1294-1300, october 2007.
6. R.Swarnalatha, "Development of Novel Techniques for Fetal ECG Extraction in Early Pregnancy," Pilani, 2010.
7. M. B. I. Reaz, M. I. Ibrahimy, M. S. Hussain, and J. Uddin M. A. Hasan, "Detection and Processing Techniques of FECG Signal for Fetal Monitoring," *Biological Procedures Online*, vol. 11, no. 1, pp. 263-295, 2009.
8. Khaled Assaleh, "Extraction of Fetal Electrocardiogram Using Adaptive Neuro-Fuzzy Inference Systems," *IEEE Transactions on Biomedical Engineering* , vol. 54, no. 1, pp. 59-68, 2007
9. Berk, and Cemal Kavalcioglu Dagman, ""Filtering Maternal and Fetal Electrocardiogram (ECG) Signals using Savitzky-Golay Filter and Adaptive Least Mean Square (LMS) Cancellation Technique," 2016.

Published By:
Blue Eyes Intelligence Engineering & Sciences Publication (BEIESP)

10. Jebila S Remi D, "Extended State Kalman Filtering Based Fetal ECG, Maternal ECG Extraction & Estimate The Maternal Blood Pressure using Single Channel Recordings," *International Journal of Computer Science and Mobile Computing*, vol. 3, no. 4, pp. 1233-1239, April 2014.
11. Jayasubha R Y, Dr. S. Krishna Kumar M. Manikandan, "Fetal Heart Monitoring from Maternal ECG," *International Journal of Scientific & Technology Research*, vol. 5, no. 3, pp. 164-166, March 2016.
12. Amita Dessai Adpaikar Shruthi Vasudev, "Extraction of Fetal ECG Parameterfrom the Composite Abdominal Signal," *International Journal of Innovative Research in Electrical, Electronics, Instrumentation and Control Engineering*, vol. 4, no. 2, pp. 193-195, April 2016.
13. Rajesh Mehra Nidhi Rastogi, "Analysis of Savitzky-Golay Filter for Baseline Wander Cancellation in ECG
14. J. O., Alamu, F. O., Opiarighodare, D. K., & Adewusi, E. A. Emuoyibofarhe, "Extraction of Fetal Electrocardiogram using an Adaptive Neuro-Fuzzy System. Extraction," *Network and Complex Systems*, vol. 4, no. 1, pp. 13-22, 2014.
15. Georgeta-Mihaela Ungureanu, Ilinca Gussi, Rodica Strungaru and Werner Wolf Dragos -Daniel tarslungs, "Fetal ECG Extraction from Abdominal Signals: A Review on Suppression of Fundamental Power Line Interference Component and Its Harmonics," *Computational and Mathematical Methods In Medicine*, 2014.
16. Amaral LAN, Glass L Goldberger AL. (2018, june20) www.physionet.org. [Online]. https://physionet.org/cgi-bin/atm/ATM
17. Shashwati Ray Om Prakash Yadav, "ECG Signal Approximation using Lagrange –Chebyshev Polynomials," *Jour of Adv Research in Dynamical & Control Systems*, vol. 10, no. 6, pp. 718-723, May 2018.
18. Shashwati Ray Om Prakash Yadav, "An Efficient ECG Approximation using Chebyshev Polynomial Interpolation," *International Journal of Innovative Technology and Exploring Engineering*, vol. 8, no. 3, pp. 16-22, January 2019.
19. Yunde Zhong, and Menachem H. Graupe Daniel Graupe, "Extraction of Fetal ECG From Maternal ECG Early In Pregnancy," *IJBEM*, vol. 7, no. 1, pp. 166-168, 2005
20. Kotas Marian, "Combined Application Of Independent Component Analysis And Projective Filtering To Fetal ECG Extraction," *Biocybernetics and Biomedical Engineering* , vol. 28, no. 1, pp. 75-93, 2008.
21. Reza, and Gari D. Clifford Sameni, "A Review of Fetal ECG Signal Processing; Issues and Promising Directions," *The Open Pacing, Electrophysiology & Therapy Journal* , p. 4, 2010.
22. Ronald W. Schafer, "What is a Savitzky-Golay filter?," 2011.
23. Md Abdul, Sheikh Shanawaz Mostafa, and Mohiuddin Ahmad Awal, "Performance Analysis Of Savitzky-Golay Smoothing Filter using ECG Signal," *International Journal of Computer and Information Technology*, vol. 1, no. 02, pp. 24-29, 2011.
24. Zhiheng, and Kaiyong Yang. Zhou, "Fetal Electrocardiogram Extraction and Performance Analysis," *Journal of Computers*, vol. 7, no. 11, pp. 2821-2828, November 2012.
25. Baby Paul, Arun A. Balakrishnan Prasanth K., "Fetal ECG Extraction using Adaptive Filters," *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering*, vol. 2, no. 4, pp. 1483-1487, April 2013.
26. Mohammad, Bertrand Rivet, and Christian Jutten Niknazar, "Fetal ECG Extraction by Extended State Kalman Filtering Based on Single-Channel Recordings," *IEEE Transactions on Biomedical Engineering* , vol. 60, no. 5, pp. 1345-1352, 2013.
27. Using Wavelets," *International Journal of Engineering Sciences & Emerging Technologies*, vol. 6, no. 1, pp. 15-23, August 2013

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication (BEIESP)