

# Review on FECG Signal Extraction

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**ABSTRACT:** Monitoring of FHR patterns is an established way of fetal surveillance and offers important information about health of the unborn. The acquisition of FECG becomes a demanding task since it is death-defying for a direct contact over the foetus. Fetal electrocardiogram (ECG) waveform analysis is performed with the measurement of electrical activity from fetal heart and has developed over the last 3 decades. The FECG can be measured by placing electrodes on the mother's abdomen. However, it has very low power and is mixed with several sources of noise and interference. The FECG signal emphasizes the foetal heart activity, which is very vital to determine the foetal heart rate (FHR), foetal development, foetal maturity, and existence of foetal distress or, analyze multiple births, to prevent the neonatal disease and to perform parametric analysis of the foetal heart. This paper reviews the existing algorithms employed for FECG extraction.

**KEYWORDS:** electrocardiogram(ECG), fetal ECG(FECG), maternal ECG(MECG), abdominal ECG(MECG),

## 1. INTRODUCTION

The Fetal electrocardiogram (ECG) waveform investigation is carried out by means of estimation of the electrical activity from the fetal heart and has been in vogue for the past thirty years witnessing gradual growth during the period. It is effectively determined by way of inserting the electrodes into the abdomen of the mother. Nevertheless, it tends to have inferior power and is blended by various sources of noise and interference. The electrocardiogram (ECG) has, over the years, established itself as the easiest and most effective noninvasive diagnostic approach intended for a host of diverse heart ailments. The Fetal ECG (FECG) signal, in turn, mirrors the electrical function of the fetal heart and elegantly offers beneficial data on its physiological condition. The non-invasive FECG is effectively utilized to realize fruitful clinical data on the fetal been used to obtain valuable clinical information about the fetal state in the course of the pregnancy by effectively using the skin electrodes inserted into the maternal abdomen.

### A. FECG EXTRACTION:

The extraction of the hygienic fetal electrocardiogram (ECG) signals has emerged as a highly critical factor in the fetal monitoring. (Shucaï Wu *et al.* 2013) shrewdly spelt out the salient features of the LMS adaptive filtering technique which are shown below.

(1) The LMS invariably achieved higher levels of perfection in the case of superposition of the R-peaks of fetal ECG and maternal ECG. (2) It effectively steered clear of the noise interruption by means of the integration of the SSNF technique, which resulted in the extraction of further robust waveforms. (3) The efficiency in accomplishment of the technique was well-established quantitatively with the help of the SNR estimation. Further, it exemplified the deployment of the reconfigurable system for the fetal electrocardiogram (FECG) evaluation.

(D.P. Morales *et al.* 2013) deftly proposed an innovative system by employing a reconfigurable system for the fetal electrocardiogram (FECG) evaluation from the ECG estimations of the abdomen of the mother. The novel technique invariably depended on two divergent reconfigurable devices. At the outset, a field-programmable analog array (FPAA) tool was entrusted with the task of performing the analog reconfigurable preprocessing for the purpose of the ECG signal attainment. The signal processing chain was extended into a field-programmable gate array (FPGA) gadget, which was home to the entire set of the transmission and interfacing protocols together

with the exact digital signal processing blocks needed for the basic period extraction from the fECG waveforms. The synergy between these contrivances empowered the system with the necessary skills to adapt any crucial constraint in the course of the acquirement function for the purpose of achieving a superior outcome. The effective employment of the FPGA went a long way in performing various techniques intended for the fECG signal extraction, like the adaptive signal filtering.

(D.J. Jagannath et al. 2014) brilliantly introduced two novel techniques such as the foetal scalp electrode (invasive) and maternal abdomen skin electrode (non-invasive) devoted to the achievement of the fECG. Out of the two the former approach viz. the Foetal scalp electrode technique was hazardous to the foetal. The scalp electrodes to be inserted on the head of the foetus after passing through the womb of the mother, was, really an exceedingly dangerous process. The relative technique was injurious to the mother as it was likely to rip the womb, trigger contagion in the interior of the womb or bloodshed in addition to being detrimental it was perilous to the foetus as well, as it caused undue pressure on the head of the foetus, infection, and cast gloom on the security of the foetus safety and the like. Striking a different note, the maternal abdomen skin electrode emerged as an ideal candidate with several merits such as easiness, noninvasiveness and the feasibility for use in the course of labour.

(Chandan Karmakar et al. 2015) proficiently proposed that CTG derived fetal heart rate time-series do not qualify for the beat-to-beat examination, which emerges as clinically more important than the long-term measure. The Fetal magneto-cardiogram (fMCG) effectively overpowered the drawbacks of the CTG and elegantly offered a non-invasive technique for examining the fetal cardiac function with adequate accuracy. Nevertheless, the fMCG invariably needed the magnetically shielded rooms (MSR), which restricted the normal deployment of the device on account of elevated expenditure of the MSR materials. Similar to the fMCG, the fetal electrocardiogram (fECG) represented a non-invasive technique for analyzing the beat-beat fetal cardiac function with enough accuracy. Even though, the extraction of the fECG was very hard, the blind source separation with reference signals (BSSR) approach was envisaged for the steady and consistent extraction of the fECG. Hence, fECG was considered as the easy and expedient technique for the non-invasive scrutiny of the fetal cardiac function.

## II. LITERATURE REVIEW

### A. ARTIFICIAL INTELLIGENCE TECHNIQUES IN FECCG EXTRACTION:

(D.J. Jagannath and A. Immanuel Selva kumar 2015) proficiently proposed that the non-invasive fECG signal could be extracted with the maximum possible efficiency. With the intention of helping the physicians they envisioned an innovative intrapartum monitoring method known as the STAN (ST analysis) for effectively predicting the intrapartum foetal hypoxia. Nevertheless, the vital dilemma was that the non-invasive fECG signals recorded from the maternal abdomen were adversely affected by various interferences as follows.

- ❖ Power line interference
- ❖ Baseline drift interference
- ❖ Electrode motion interference
- ❖ Muscle movement interference
- ❖ The mECG dominant interference.

Further, they flagged off a ground-breaking approach known as the BANFIS (Bayesian adaptive neuro fuzzy inference system). The novel BANFIS technique was home to a Bayesian filter and an adaptive neuro fuzzy filter for the eradication of the mECG and non-linear artefacts so as to bring in superior quality fECG signal.

(M. S. Amin et al. 2011) amazingly launched an adaptive method for the purpose of extracting FECCG by employing an innovative adaptive linear neural network (ADALINE) for the trouble-free fetal scrutiny in which the suitable learning rate, momentum and initial weights were employed to harmonize the network error till it became equivalent to the fetal ECG. Their novel technique achieved superlative precision when the constraints such as the learning rate(LR), momentum(M), and initial weights(IW) were estimated by means of specified values like high LR, Low M and Small IW.

(Maryam Nasiri et al. 2011) majestically launched an Adaptive Neuro-Fuzzy Inference System (ANFIS) to examine and locate the nonlinear high frequency components of maternal Electrocardiogram (MECCG). The Particle Swarm Optimization (PSO) was treated as one of the highly sophisticated device meant for training the

ANFIS structure which recognized the nonlinear components of MECG (transformation) while training the input AECG data and subsequently effectively eradicated the associated edition of the MECG signal from the noise free abdominal ECG (AECG) signal extorted by the FECG.

**Table1. Artificial intelligence techniques in FECG extraction:**

Author name and year	Method	Function	Pros and cons
D.J. Jagannath and A. Immanuel Selvakumar 2015	BANFIS (Bayesian adaptive Neuro fuzzy Inference system) method	The BANFIS effectively carries out the function of eradicating the ECG and non-linear artefacts with the intention of achieving excellent quality fECG signal.	Superior quality fECG elicitation and the capability of the system to adjust towards the adaption of various constraints leading to the effective removal of redundant interference and noise from the electrocardiogram signals
M. S. Amin et al. 2011	Adaptive linear neural network (ADALINE)	The network follows the maternal signal intimately to the abdominal signal, thereby forecasting only the maternal ECG in the abdominal ECG.	<ul style="list-style-type: none"> <li>❖ Superb learning rate</li> <li>❖ Insignificant momentum</li> <li>❖ Very low primary weights.</li> </ul>
Maryam Nasiri et al. 2011	Adaptive Nero-Fuzzy Inference System (ANFIS)	ANFIS effectively gathers the skills of the neural networks and fuzzy systems in learning the non-linearities.	ANFIS represents a Dependable device for ascertaining the non linear conversion.

**B. WAVELET TRANSFORM BASED FECG EXTRACTION APPROACHES:**

An innovative pattern for the fetal heart rate (FHR) examination from single-lead mother’s abdomen ECG (AECG) measurements was enlightened by (E. Castillo et al. 2013). The proposed technique passed through the following two phases.

- ★ In the former phase, a single-step wavelet-based preprocessing was performed for instantaneous baseline and high-frequency noise repression
- ★ In the latter phase, effective identification of the fetal QRS complexes was accomplished, thereby facilitating the FHR scrutiny.

The offered framework was further simplified to the extent feasible, with the intention of significantly scaling down the computational expenses, thereby facilitating the potential custom hardware accomplishments. Further, the innovative technique its fixed point modeling were extensively investigated with the deployment of the genuine abdominal ECG signals, thereby enabling the

authentication of the novel technique and also leading superior precision.

A concurrent fetal electrocardiogram (FECG) feature extraction technique dependent on multi-scale discrete wavelet transform (DWT) was flagged off by (K.D. Desai and Manoj S. Sankhe 2012). The wavelet based peak recognition was employed to identify the QRS complex further precisely for detecting the ups and downs of the noise-polluted FECG signal. Further, the two channel perfect reconstruction (PR) filter banks were employed to efficiently perform the discrete wavelet transform. The expanded fetal maternal ECG monitor machine was effectively investigated in a local hospital on a sample group of 35 pregnant women at various intervals in the course of the gestation period. Their consistent system was able to identify the entire FECG beats with an incredible accuracy to the tune of 99.5 % while taking into account the restraints in the measuring system parameters in the five minutes recording of each subject.

(Neha Dhage and Swati Madhe 2014) brilliantly brought to limelight an innovative mechanized technique for the extortion of the Fetal Electrocardiogram (FECG) from the abdominal electrocardiogram (AECG) recording. The FECG represented a feeble signal from the maternal ECG indirectly evaluated by the surface electrode inserted in the abdomen of the mother. The Fetal signals were buried in the other interference signal. The extraction of the FECG from the strong background interference was a very valuable factor in the clinical application.

However, a number of investigation works have been carried out in this domain, a few of which include the following.

- ❖ Threshold and Filtering technique
- ❖ Neural Network technique
- ❖ Wavelet Transform and others.

The innovative technique included the Independent Analysis technique for FECG extraction. Fundamentally, the ICA functions in diverse constraints such as the Kurtosis and Negentropy. In the current investigation, the focus is on the Negentropy, where subsequent to the extraction of FECG signal the Fetal R-peak are identified by means of the threshold free identification technique involving the R-R moving interval, estimated as per the normal maximum and minimum heart rate.

**Table2. Wavelet transform based FECG extraction**

Author name and year	Method	Function	Pros and cons
E. Castillo et al. 2013	Wavelet based method	Concurrent baseline and high-frequency noise Containment, effective identification of the fetal QRS complexes facilitating the FHR supervision.	Significantly scales down the computational expenses, thereby resulting in the potential custom hardware performances.
K.D. Desai and Manoj S. Sankhe 2012	Multi-scale discrete wavelets transform (DWT).	The DWT elegantly utilizes a dyadic grid (integer power of two scaling in a and b) and ortho normal Wavelet basis functions and demonstrates absence of redundancy.	The discrete wavelet based peak identification approach effectively employs the method utilizes the intrinsic multi-faceted character of the wavelet examination and is found to be incredibly vigorous and precise in relation to the threshold or curve – fitting dependent peak recognition approach
Neha Dhage and Swati Madhe 2014	Independent Analysis technique	The ICA effectively segments the FECG signal from MECG signal	The average precision and The average positive predictivity of the identification technique is moderately superior.

**C. SVD, ICA BASED APPROACHES FOR FECG EXTRACTION:**

The Blind source separation effectively segregates the mixed signals, without the assistance of any previous knowledge regarding the source signals. The factorization of genuine or complex matrix is known as the Singular value decomposition, which is largely employed in the signal separation. The Independent component analysis represents a novel approach which can be performed for the separation of a multivariate signal into additive subcomponents.

(Xinling Wen et al. 2013) effectively employed the ICA based BSS techniques for the extortion of the FECG, in which ICA used the superior order statistics resulting in the computational intricacy. ICA based technique for the FECG extraction and MECG annulment, functioned effectively in the absence of Signal to Noise

ratio equal to -200 db without quantification of the noise and similarly the efficiency of the system went down with quantification.

### III. ADAPTIVE FILTERING BASED FECG EXTRACTION APPROACHES

An adaptive filter constitutes an effective filter which self-adapts its transfer function on the basis of an optimization technique motivated by an error signal. In this regard, diverse categories of the adaptive filters have been extensively employed for the purpose of the fetal and maternal signal separation. The corresponding techniques invariably employ one or more reference maternal signals for training an adaptive or harmonized filter, or directly training the filter devoid of the reference signal for the extortion of the fetal QRS waves. The Kalman filter which symbolizes a universal class of adaptive filters extensively employed, utilizes only a random MECG as reference for the MECG annulment and FECG extortion. The temporal dynamics of AECG signals are modeled or AECG signals are synthesized depending on the compilation of the state-space equations and Bayesian filter which has been employed for the purpose of the ECG denoising. However, the filter miserably fails to distinguish between the maternal and fetal components when both are completely overlapped in time. When the waves of varied signals completely overlap in time it is very difficult to filter out the preferred ECG employing the relative filter.

#### A. MULTISTAGE ADAPTIVE FILTER FOR FECG EXTRACTION:

An enhanced technique launched by (R.Swarnalatha and D.V.Prasad 2010) effectively employs the multistage adaptive filtering for the FECG extraction in which MECG annulment is performed taking into account have thoracic ECG as reference signal. Further the denoising techniques have been elegantly employed to augment the quality of extracted signal. Usually, the adaptive filter is in need of 2 input signals as shown below.

- ❖ AECG signal
- ❖ Thoracic ECG

Here thoracic ECG is adapted by means of the scaling and squaring. Scaling factors are selected in such a way as to attune the adaptive filters to accomplish the extraction. A shining quality of the novel technique is that the input thoracic signal need not necessarily be original which is gathered from the pregnant woman whose AECG has been furnished as primary input together with this, and even intimately identical signal may also be taken into account. In this regard, three diverse techniques are employed for the self adapting filter such as the LMS,RLS,NLMS for the purpose of augmenting the SNR ratio by suitably adapting the filter coefficients .

#### B. ADAPTIVE NOISE CANCELLER FOR FECG EXTRACTION:

(Prasanth K et al. 2013) They have deeply discussed the elimination of background noise and artifacts from the FECG signals employing the adaptive filters which involve the application of two input signals as detailed below.

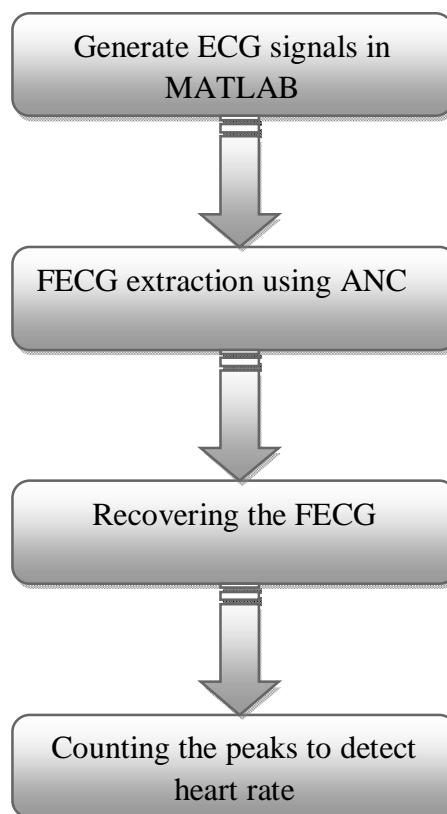
- \* The primary signal represents the FECG signal combined with the MECG signal
- \* The secondary signal characterizes the reference signal which is the noise to be annulled such as the MECG signal.

The secondary noise signal has to be effectively associated with the noise in the primary signal. The adaptive filters are effectively utilized in the fetal electrocardiography, wherein a maternal heartbeat signal is adaptively detached from a fetal heartbeat signal. In an adaptive filter functioning in a motionless scenario, the error-performance surface possesses a fixed form and orientation. When the adaptive filter functions in a moving scenario the bottom of the error performance surface frequently moves whereas the orientation and curvature of the surface also undergo certain changes. Hence, when the inputs are moving, the adaptive filter performs the function of looking for the bottom of the error performance surface, and also incessantly tracking it.

#### C. KALMAN FILTERS FOR FECG EXTRACTION:

(Mohammad Niknazar et al. 2013) have flagged off the Kalman filtering (KF) framework which is deemed as a member of the universal class of adaptive filters, in addition to being a prospective technique for the annulment of the mECG and the enrichment of the fECG. A set of state-space equations are effectively employed to fashion the temporal dynamics of ECG signals, for devising a Bayesian filter for the purpose of ECG denoising. The captioned

Bayesian filter structure is effectively utilized to extract the fECG from single channel blend of the mECG and fECG. Nevertheless, the filter has miserably failed to distinguish between the maternal and fetal components when the mECG and fECG waves entirely overlap in time. It is because of the fact that when mECG is evaluated, the fECG and the parallel components are deemed to be the Gaussian noises.



**Fig. Algorithm for FECG extraction**

**D. TRANS-ABDOMINAL FETAL ELECTROCARDIOGRAM:**

(Tamara Stampalija et al. 2015) They have performed the ta-fECG recordings with the help of the AN24 fetal ECG monitor in the serene scenarios in the utero. The electro-physiological signal invariably comprises the following elements.

- \* Maternal ECG
- \* Fetal ECG
- \* Electro-hysterogram

It is recorded with a sample frequency of 900 Hz employing 5 disposable electrodes positioned on the maternal abdomen in a homogeneous way. The technique employed for the extraction of the fetal ECG signal and examination is elaborately elucidated. The Fetal ECG complexes are effectively utilized to evaluate the R-R pulse intervals with an accuracy of about 1 ms. The STV (in ms) is estimated from the obtained R-R intervals in accordance with the investigation recordings with signal loss >50% are eliminated from additional examination.

**E. RMI EXTRACTION:**

It is easily feasible to visually locate the RMI as a noise superposition on top of the ECG. A simple method for its extraction is the ultimate abandonment of the ECG. Recently, a novel cancellation technique has been envisaged in the backdrop of the non-invasive fetal ECG extraction by (Maier C, Dickhaus H 2013) which may be effectively

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employed for the extraction of the RMI. The related process commences right from the baseline- and power line filtered raw ECG signals. At the outset, a template (average cardiac cycle) is generated and incessantly reduced from the ECG. The remaining inconsistency linked to the ECG waves is additionally attenuated by the eradication of the leading principal components of the vector ensembles which are obtained from several epochs encompassing the QRS-complex ([R-100 ms; R + 100 ms]), P-wave ([R-300 ms; R-100 ms]) and T-wave ([R + 100 ms; R + 500 ms]). With an eye on quantifying the vigor of RMI, a time-variant measure of variability has to perform on this signal. The unrefined RMI signal envelope characterizes an instant index of RMI strength with the time resolution of the ECG. The raw RMI signal standard deviation (SD) is evaluated in a sliding windows of 100 ms width, the reasons for which will be elucidated later.

**IV. CONCLUSION**

The fetal electrocardiogram (FECG) had its humble origin as long back as the year 1901, when the preliminary growth of investigation in the related domain was considerably restricted. With the onset of enhanced amplifiers and filters, the identification of the waveform was significantly simplified, though the surveillance of the waveform morphology was a complicated issue thanks to then-prevalent background noise subsequent to the filtering of the tainted signal. The signal-to-noise ratio of the original FECG was incredibly enhanced by means of the effective signal processing and computer technologies albeit the non-invasive attainment of the signals. The document elegantly exhibits the assessment of a host of approaches extensively employed for the extraction of fetal ECG extraction till now.

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