An Appraisal on FECG Elicitation

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Abstract— Observation of Fetal Heart Rate (FHR) is an effective method for fetal reconnaissance and offers vital data about wellbeing of the unborn. The procurement of FECG turns into a tedious work since it is death-challenging for an immediate contact over the fetus. Fetal electrocardiogram (ECG) waveform examination is performed with the estimation of electrical action from fetal heart and has created in the course of the last 3 decades. The FECG can be estimated by fixing electrodes on the mother's abdominal region. In any case, it has low power and is contaminated with various noises and interference. The FECG signal illustrates fetal heart action, which is exceptionally imperative to detect the FHR, fetal growth and presence of fetal disorder or investigate multiple births, to prevent neonatal disease and to perform parametric examination of the fetal heart. This paper surveys the current methodologies utilized for FECG extraction.

Key words: Electrocardiogram (ECG), Fetal ECG (FECG), Maternal ECG (MECG), Stomach ECG (MECG)

I. INTRODUCTION

The Fetal electrocardiogram (ECG) waveform analysis is performed by estimation of electrical action from the fetal heart and has been in vogue for as far back as thirty years seeing continuous development amid the period. It is successfully detected by method of applying the electrodes into abdomen of the mother. However, it seems to possess lesser power and is mixed by different noises. The electrocardiogram (ECG) has, throughout the years, built up itself as the trivial and best noninvasive diagnostic methodology projected as a hub for various heart abnormalities. The Fetal ECG (FECG) reflects the electrical activity of the fetal heart and exquisitely offers gainful information on its physiological condition. The non-invasive FECG is successfully used to acknowledge productive clinical information on the fetal been utilized to get significant clinical data about the fetal state throughout the period of pregnancy by viably utilizing the skin electrodes embedded into the maternal abdomen.

II. FECG EXTRACTION

The extraction of the clean fetal electrocardiogram (ECG) signals has risen as an exceptionally basic factor in the fetal investigation. (Shuicai Wu et al. 2013) intelligently spelt out the significant features of the LMS adaptive filtering procedure which are demonstrated as follows.

(1) The LMS constantly accomplished high accuracy in scenario of superposition of the R-peaks of fetal ECG and maternal ECG. (2) It viably avoided the noise interference by methods for the mix of the SSNF method, which brought about the extraction of further tough waveforms. (3) The productivity in achievement of the method was entrenched quantitatively with the assistance of the SNR estimation. Further, it exemplified the implementation of the reconfigurable framework for the fetal electrocardiogram (FECG) assessment.

(D.P. Morales et al. 2013) deftly proposed an inventive method by utilizing a reconfigurable system for the fetal electrocardiogram (FECG) assessment from the ECG estimations of the mother's abdomen. The original method constantly relied upon two distinct reconfigurable devices. At the starting, a field-programmable analog array (FPAA) device was assigned with the job of the doing analog reconfigurable preprocessing with the end goal of the ECG signal acquisition. The signal processing chain was stretched out into a field-programmable gate array (FPGA) device, which was home to the whole arrangement of the transmission and interfacing protocols together with the appropriate digital signal processing blocks required for the fundamental period extraction from the FECG waveforms. The collaboration between these methods enabled the system with the essential abilities to adjust to any imperative restrction over the span of the procurement work to achieve a predominant result. The compelling work of the FPGA went far in performing different strategies planned for the FECG signal extraction, similar to the adaptive signal filtering.

(D.J. Jagannath et al. 2014) splendidly presented two novel methods like the fetal scalp electrode (Invasive) and mother's abdomen skin electrode (non-invasive) committed to the accomplishment of the fECG. Out of the two the previous methodology viz. the fetal scalp electrode procedure was risky to the fetus. The scalp electrodes to be fixed on the head of the fetus after going through the womb of the mother, was, extremely an exceedingly perilous process. The relative procedure was damaging to the mother as it was probably going to tear the womb, trigger infection in the inside of the womb or bloodshed. Striking an alternate note, the mother's abdomen skin electrode developed as a perfect method with many advantages like ease, noninvasiveness and the practicality for use over the span of labour.

(Chandan Karmakar et al. 2015) expertly suggested that CTG determined FHR time-series do not fit for the beat to-beat analysis, which rises as clinically more essential than the long duration measurement. The Fetal magneto-cardiogram (fMCG) viably overwhelmed the demerits of the CTG and exquisitely offered a non-invasive system for looking at the fetal cardiac activity with sufficient accuracy. In any case, the fMCG perpetually required the magnetically shielded rooms (MSR), which confined the typical usage of the device on basis of high expenses of the MSR materials. Like the fMCG, the fetal electrocardiogram (fECG) put forth a non-invasive procedure for examining the beat-beat fetal cardiac activity with enough precision. Despite the fact that, the extraction of the fECG was hard, the blind source seperation with reference signals (BSSR) approach was envisioned for the relentless and predictable extraction of the

fECG. Henceforth, fECG was considered as the simple and practical procedure for the non-intrusive examination of the fetal heart work.

III. LITERATURE REVIEW

A. *Artificial Intelligence Techniques in FECG Extraction*

(D.J. Jagannath and A. Immanuel Selva kumar 2015) intelligently recommended that the non-invasive FECG signal could be separated with the most extreme compliable accuracy. With the goal of helping the doctors they thought of a creative intrapartum examining technique known as the STAN (ST investigation) for adequately anticipating the intrapartum fetal hypoxia. However, the important concern was that the non-invasive fECG signals recorded from the mother's abdomen were antagonistically influenced by different Interferences as pursues,

- Power line Interference
- Baseline drift
- Electrode motion Interference
- Muscle movement Interference
- The mECG Interference.

Further, they hailed off an earth shattering methodology known as the BANFIS (Bayesian adaptive neuro fuzzy Inference System). The epic BANFIS method was host to a Bayesian filter and an adaptive neuro fuzzy filter for the elimination of the mECG and non-linear artefacts in order to get predominant quality fECG signal.

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.	❖ Superb learning rate ❖ Insignificant momentum ❖ Very low primary weights.
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.

Table 1: Artificial Intelligence Techniques in FECG Extraction

- In the previous stage, a single-step wavelet-based preprocessing was performed for immediate baseline and high-frequency noise suppression
- In the last stage, efficient estimation of fetal QRS complexes was cultivated, so as to encourage the FHR examination.

The offered structure was additionally improved to the maximum extent, with the expectation of altogether downsizing the computational costs, in this way encouraging the potential custom hardware achievements. Further, the creative method, fixed point modelling were widely examined with the usage of the veritable abdominal ECG signals, in this manner empowering the validation of the novel strategy and furthermore driving predominant accuracy.

(M. S. Amin et al. 2011) incredibly propelled an adaptive strategy to extract FECG by utilizing a creative adaptive linear neural network (ADALINE) for the stress-free fetal examination in which the reasonable learning rate, momentum and beginning weights were utilized to synchronize the network error until achievement of fetal ECG. Their epic system accomplished superlative accuracy when the parameters like learning rate (LR), momentum (M), and initial weights (IW) were assessed by ways of fixed values like high LR, Low M and Small IW.

(Maryam Nasiri et al. 2011) magnificently propelled an Adaptive Nero-Fuzzy Inference System (ANFIS) to inspect and find the nonlinear high frequency parts of maternal Electrocardiogram (MECG). The Particle Swarm Optimization (PSO) was treated as one of the exceedingly refined gadget implied for training the ANFIS structure which perceived the nonlinear segments of MECG (transformation) while training the input AECG data and in this manner viably annihilated the related version of the MECG signal from the noise abdominal ECG (AECG) signal extorted by the FECG.

B. *Wavelet Transform Based FECG Extraction Approaches*

A creative pattern for the FHR examination from single-lead mother's abdomen ECG (AECG) estimations was illuminated by (E. Castillo et al. 2013). The proposed procedure went through the accompanying two stages.

A simultaneous fetal electrocardiogram (FECG) feature extraction method reliant on multi-scale discrete wavelet transform (DWT) was hailed off by (K.D. Desai and Manoj S. Sankhe 2012). The wavelet based peak recognition was utilized to determine the QRS complex further accurately to recognize the high and low of the noise-contaminated FECG signal. Further, the two channel perfect reconstruction (PR) filter banks were utilized to productively do the discrete wavelet transform. The extended fetal maternal ECG monitor machine was viably examined in a neighborhood hospital facility on a sample group of 35 pregnant ladies at different time slots over the span of the gestation period. Their predictable framework could distinguish the whole FECG beats with a mind boggling accuracy of 99.5 % while considering the restrictions in the estimating system parameters in the five minutes recording of each subject.

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.

Table 2: Wavelet Transform based FECG Extraction

The attention is on the Negentropy, where consequent to the extraction of FECG signal the Fetal R-peak are distinguished by methods for the threshold free estimation strategy including the R-R moving interval, evaluated according to the ordinary most extreme and least heart rate.

C. SVD, ICA Based Approaches For FECG Extraction

The Blind source partition successfully isolates the blended signals, without the help of any past information in regards to the source signals. The factorization of real or complex matrix is known as the Singular value decomposition, which is generally utilized in the signal partition. The Independent component analysis serves as a novel methodology which can be performed for the seperation of a multivariate signal into additive subcomponents.

(Xinling Wen et al. 2013) viably utilized the ICA based BSS methods for extraction of the FECG, in which ICA utilized the superior order statistics bringing out the computational difficulties. ICA based procedure for the FECG extraction and MECG elimination, worked viably without Signal to Noise ratio equivalent to - 200 db without quantification of the noise and comparatively the efficiency of the framework ran down with quantification.

IV. ADAPTIVE FILTERING BASED FECG EXTRACTION APPROACHES

An adaptive filter comprises a successful filter which self-adjusts its Transfer function based on an optimization technique spurred by an error signal. In such manner, various classes of the adaptive filters have been broadly utilized with the end goal of the fetal and maternal signal separation. The appropriate methods assigns at least one reference maternal signals for training an adaptive or synchronized filter, or straightforwardly training the filter without the reference signal for the extraction of fetal QRS waves. The Kalman filter which symbolizes an all-inclusive class of adaptive filters broadly utilized uses just an arbitrary MECG as reference for the MECG exclusion and FECG extraction. The temporal dynamics of AECG signals are modeled or AECG signals are designed relying upon the accumulation of the state-space equations and Bayesian filter which has been utilized with the end goal of the ECG denoising. In any case, the filter fails to recognize the maternal and fetal components when both are totally mixed in time. When the waves of different signals totally cover in time, it is exceptionally hard to filter the favored ECG utilizing the relative filter.

A. Multistage Adaptive Filter for FECG Extraction

An improved system propelled by (R.Swarnalatha and D.V.Prasad 2010) viably utilizes the multistage adaptive filtering for the FECG extraction in which MECG abrogation is performed considering thoracic ECG as reference signal. Further the denoising methods have been richly utilized to enlarge the quality of obtained signal. More often than not, the adaptive filter in need 2 input signals a follows.

- AECG signal
- Thoracic ECG

Here thoracic ECG is adjusted by techniques of scaling and squaring. Scaling factors are chosen so as to adjust the adaptive filters to achieve the extraction. A sparkling nature of the novel strategy is that the input thoracic signal require not really be unique which is accumulated from the pregnant lady whose AECG has been outfitted as essential input together with this, and even initimately similar signal may likewise be considered. In such manner, three different procedures are utilized for oneself adjusting channel, for example, the LMS, RLS, NLMS to augment the SNR ratio by reasonably adjusting the filter coefficients.

B. Adaptive Noise Canceller for FECG Extraction

(Prasanth K et al. 2013) They have profoundly talked about the exclusion of foundation noise and artifacts from the FECG signals utilizing the versatile channels which include the utilization of two input signals as itemized beneath.

- The primary signal represents the FECG signal joined with the MECG signal
- The secondary signal portrays the reference signal which is the noise to be removed like the MECG signal.

The secondary noise signal must be adequately connected with the noise in the primary signal. The adaptive filters are adequately used in the fetal electrocardiography, wherein a maternal heartbeat flag is adaptively separated from a fetal heart beat signal. In an adaptive filter working in an unmoving situation, the error-performance surface often moves as well as the orientation and curvature faces some changes.

Consequently, when the inputs are moving, the adaptive filter tracks the error-performance surface.

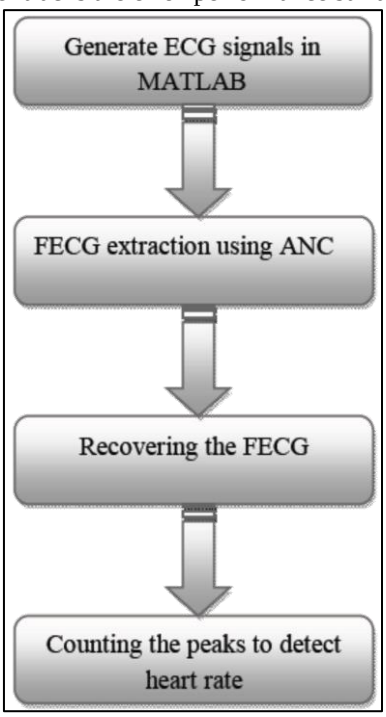

Fig.1: Algorithm for FECG Extraction

C. *Kalman Filters for FECG Extraction*

(Mohammad Niknazar et al. 2013) have hailed off the Kalman filtering (KF) system which is considered as an individual from the general class of adaptive filters, notwithstanding being a forthcoming strategy for the removal of the mECG and the enhancement of the fECG. An arrangement of state-space equations are viably utilized to mold the temporal elements of ECG signals, for designing a Bayesian filter with the end goal of ECG denoising. The inscribed Bayesian filter structure is successfully used to extricate the fECG from single channel mix of the mECG and fECG. In any case, the filter has pitiably neglected to recognize the maternal and fetal parts when the mECG and fECG waves altogether synchronize in time. It is a direct result of the way that when mECG is assessed, the fECG and the parallel parts are regarded to be the Gaussian noise.

D. *Trans-Abdominal Fetal Electrocardiogram*

(Tamara Stampalija et al. 2015) They have done the ta-Fecg recordings with the assistance of the AN24 fetal ECG monitor in the quiet situations in the utero. The electro-physiological flag constantly involves the accompanying components.

- Maternal ECG
- Fetal ECG
- Electro-hysterogram

It is recorded with a sample frequency of 900 Hz utilizing 5 dispensable electrodes placed on the maternal abdomen homogeneously. The method utilized for the extraction of the fetal ECG and examination is intricately clarified. The Fetal ECG complexes are viably used to assess the R– R pulse interval with a precision of around 1 ms. The STV (in ms) is evaluated from the gotten R– R intervals as per the examination recordings with signal loss >50% and are removed from extra examination.

E. *RMI Extraction*

It is effortlessly doable to outwardly find the RMI as a noise superposition over the ECG. A straightforward strategy for its extraction is a definitive surrender of the ECG. As of late, a novel cancellation method has been visualized in the background of the non-invasive fetal ECG extraction by (Maier C, Dickhaus H 2013) which might be viably utilized for the extraction of the RMI. The related procedure begins ideal from the baseline and power line filtered crude ECG signals. At the start, a layout (average cardiac cycle) is produced and perpetually decreased from the ECG. The rest of the irregularity connected to the ECG waves is moreover constricted by the destruction of the main Principal components of the vector gatherings which are acquired from many epochs incorporating 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 evaluating the power of RMI, a time-variant proportion of inconstancy needs to perform on this signal. The contaminated RMI signal envelope describes a instant index of RMI quality with the time resolution of the ECG. The crude RMI signal standard deviation (SD) is assessed in a sliding windows of 100 ms width, the explanations behind which will be clarified later.

V. Conclusion

The fetal electrocardiogram (FECG) had its modest inception as long back as the year 1901, when the initial development of examination in the related area was significantly confined. With the beginning of upgraded amplifiers and filters, the recognition of the waveform was essentially streamlined, however the observation of the waveform morphology was an entangled issue. The signal to noise ratio of the first FECG was amazingly improved by methods for the viable signal processing and computer advances though the non-invasive achievement of the signals. This paper carefully displays the appraisal of a large group of methodologies widely utilized for the extraction of fetal ECG extraction till now.

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