CHAPTER – V

RESULTS AND DISCUSSION

5.1 INTRODUCTION

Every innovation has its own advantages and disadvantages. These can be evaluated by making the comparison with the existing methods. These comparisons often lay the foundations for further modifications or innovations of new algorithms. This chapter discusses the advantages and the disadvantages of the proposed algorithm with the existing algorithms. The discussion is carried out in three categories. They are

- Discussion of results under fetal ECG separation methods
- Discussion of results under Noise removal methods
- Discussion of results under Fetal ECG classification methods.

5.2 FETAL ECG SEPARATION METHODS

In this work, various fetal ECG segregation techniques such as EFCIA, WASOBI, Multi-COMBI methods and FCOMBI methods were studied. The results obtained with FCOMBI methods have high SIR and PSNR values. The signal separation and enhancement done with FCOMBI algorithm was high compared to the algorithm proposed by Abed Al Raoof K. Bsoul et al. Even though both these algorithms are non-invasive study procedures, the quality of the signal obtained with the proposed algorithms is better than the other algorithm taken for the study.

The study made by Abhinav Gupta et al. concluded that ICA was the best technique in fetal ECG segregation process. But as discussed earlier, variance and the other independent components cannot be identified which become the problem, in using ICA. In order to overcome this problem a modified ICA named as EFCIA method was used in this study, and satisfactory results are obtained. The added advantage of EFCIA method is that the other independent components can also be identified with these methods.

The placement of electrodes plays a major role in deciding the quality of separated signal with the algorithm proposed by Aryan Salmanpour et al. The signal analysis can be done only on the signals that were acquired from the chest portions, whereas the proposed FCOMBI algorithm is independent of placement and the number of electrodes, which is an advantage over the other algorithm taken for the study.
The automated algorithm proposed by Ayat.M et al. uses singular value decomposition method for the separation of fetal ECG signals. The accuracy of this algorithm was 96 %. On the other hand, the proposed FCOMBI method uses the extended ICA technique for the separation of fetal ECG signals. The accuracy produced by this method of signal separation process is 96.5 percent. Moreover, the signal enhancement with FCOMBI algorithm is also more over the other methods.

The algorithm proposed by Bommpalli Madhava Reddy et al. used adaptive filtering technique for the separation of fetal ECG signals. This algorithm has high compression ratio as compared to the proposed algorithm. On the other hand, the mean square values reported by both these algorithms were almost equal.

The hardware tool developed by Chareonsak.C et al. uses Modified Torkkola's BSS technique and ICA techniques for the separation of fetal ECG signals. This tool made the fetal ECG separation process simpler than software-based BSS techniques, whereas the signal separation using FCOMBI technique made the process much simpler than the other process.

The algorithm developed by Campus.D et al. uses FIR filter and neural networks for the separation of fetal ECG signals. The least mean square and normalized least mean square values by this algorithm were also satisfactory. This algorithm as well as the proposed algorithm reported equal reliability over the other algorithms.

The OL-JADE algorithm proposed by DaniloPani et al. used least square method for the extraction of fetal ECG signals. This algorithm depends on the placement of electrodes. The proposed FCOMBI algorithm is independent of placement of electrodes. Moreover, the signal to noise ratio of the proposed FCOMBI algorithm is also high compared to the OL-JADE algorithm.

The fetal ECG signal separation method developed by Dragos D Taralunga et al. uses Event Synchronous Canceller technique for the separation of signals. The FP ratio reported by the algorithm is also less. The method of signal separation in this method is done based on the template matching methods. This method of signal separation process is a complex procedure. On the other hand, the proposed FCOMBI algorithm is a simple procedure for fetal ECG separation. The FP ratio reported with the proposed FCOMBI algorithm is also less.

The algorithm proposed by E. C. Karvounis et al. used Complex continuous wavelet transform and modulus maxima theory for the separation of fetal ECG signals.
The accuracy rate reported by the algorithm is 99.5 percent which is high compared to the proposed FCOMBI algorithm. Even though the accuracy rate reported by the FCOMBI algorithm is less compared to the other algorithm, the signal separation procedure is simple when compared to the algorithm proposed by the authors.

The recurrence plot analysis of fetal ECG procedure reported by Elif Tuba Celik et al. produced fruitful results. On the other hand, the signal to noise ratio in the separated fetal ECG signal produced by the FCOMBI algorithm is high compared to the other algorithms. The method of analysis is also much simple compared to the other algorithms.

The algorithm proposed by Elloumi et al. uses two pass pitch synchronous wavelet transform method for the separation of fetal ECG signals. This algorithm has two stages in ECG signal separation. The accuracy reported by this algorithm is also not satisfactory. The proposed FCOMBI algorithm is a single stage fetal ECG signal separation procedure. The accuracy rate reported by this proposed algorithm is also satisfactory.

The algorithm proposed by Evaggelos C. Karvounis et al. uses matching theory algorithms and complex wavelets for the separation of fetal ECG signals. The accuracy rate reported by this algorithm is 97.47 %. This accuracy is high compared to the FCOMBI algorithm which is 96.5%. Even though the accuracy is less compared to the other algorithms, it uses only single stage for fetal ECG separation whereas the other algorithms under discussion use three stages in the signal separation process.

The algorithm proposed by Fanelli et al. converted the QRS complexes into binary signals. The maternal components are suppressed from the binary signal. The accuracy rate produced by this algorithm is 93.6 %. This accuracy is less compared to the proposed FCOMBI algorithm which has an accuracy of 96.5 %. Moreover, the signal separation method with the proposed algorithm is also easy compared to the other algorithms under discussion. Both these algorithms can be used to analyze singleton and twin pregnancy subjects.

The algorithm developed by Hassan Akbari et al. used Tucker decomposition method for the separation of fetal ECG signal from the abdominal ECG signals. Improvement in the signal to noise ratio is observed with the developed algorithm. The proposed FCOMBI algorithm also made the fetal ECG signal separation more effectively. The signal to noise ratio achieved with the proposed algorithm also matches with the other algorithms under discussion. The advantage of this proposed
algorithm is that the signal separation process is much simpler than the algorithm proposed by Hassan Akbari.

The algorithm proposed by Iulian B Ciocoiu et al. used K-SVD algorithm for the separation of fetal ECG signals. The results produced by this algorithm are much comparable to the other earlier algorithms. But effective results were obtained only with the signals that are acquired from single ECG electrodes, whereas the proposed algorithm is independent of both the number and the placement of electrodes. This is an advantage of the proposed algorithm over the others.

The algorithm proposed by Ivaylo Christov et al. used various steps for the separation of fetal ECG signals from the maternal signals. The algorithm produced average scores of 285.132 for events 1 and 4 for FHR measurement, 19.962 for events 2 and 5 for fetal RR interval measurement. Even though these results are satisfactory, the algorithm is restricted to analysis of signal maximum up to four electrodes. On the other hand, the proposed algorithm produced a higher accuracy of 96.53 % and is also independent of number of the electrodes used for signal acquisition.

The algorithm proposed by Jakub Kuzilek and Lenka Lhotska produced satisfactory maternal cancellation. The cancellation procedure was done based on Christov's beat detection algorithm. The results achieved with this algorithm was 249.784 and 21.989 for event 1/4 and 2/5 respectively. Even though the results obtained are satisfactory, the method of signal separation process is complex compared to the proposed algorithm. Moreover the specificity and the sensitivity rate achieved with the proposed algorithm are also much satisfactory compared to the other algorithms under discussion.

Jenho Tsao et al. developed an algorithm for the separation of fetal ECG signals from the maternal ECG. The developed algorithm was named as supervised ICA algorithm. The other blind source algorithms were unsupervised algorithms. In the proposed algorithm by the authors, the temporal structure of the desired signal was encoded in the system. By making the comparison between the stored signal and the abdominal ECG signal, the extraction of fetal ECG signal was made. This algorithm can be extended for the extraction of fetal ECG signals from multichannel ECG recordings.

The algorithm proposed by K. T. Assaleh et al. was a much simpler process in the extraction of fetal ECG signals. The resultant of this algorithm also yielded pure fetal ECG signal. But this algorithm was restricted to analysis of signals that were
acquired from two electrodes. But the proposed algorithm is independent of the number of electrodes used for signal acquisition. The proposed FCOMBI fetal ECG signal separation method is also much simple like the other methodologies under discussion.

The FCOMBI algorithm used in this work produced much effective fetal ECG signal separation compared to the template matching technique used by Kuei-Chiang Lai et al. The method of signal separation by FCOMBI algorithm is also much easier than the other. This is because the other method of signal separation under discussion mainly depends on the amplitude of the weaker signal. The weaker amplitude has to be defined by the user in the method of analysis. But the proposed algorithm does not need any predefined parameters for signal separation.

The results obtained with the FCOMBI algorithm in signal separation produced satisfactory results over the algorithm suggested by Lee J and Cho S.P which used wavelet transform and ICA for signal separation. The latter algorithm performs well on the synthetic generated signals than real-time signals. But the proposed algorithm performed well with both synthetic and real-time signals in the noise removal process.

The results obtained with FCOMBI algorithm in this proposed work produced much improved results than the PCA technique and ICA technique used by Luis Omar et al. on abdominal ECG signals. The PSNR values obtained with the proposed algorithm is 7.927071 which is high compared to the other two techniques in this discussion.

The FCOMBI algorithm produced a PSNR of 102.922251 and MSE of 0.031947 with the abdominal ECG signals. These values reveal that the signal separation with FCOMBI algorithm is much effective. The same is confirmed with conclusion results given by Luis Sarmiento et al. The authors made a study on various signal separation techniques such as COMBI, MULTI-COMBI, JADE and EFCIA methods. The authors also concluded that COMBI and MULTI COMBI algorithms perform well over the other two methods. But the observation made in this proposed work reveals that the FCOMBI algorithm performs much better than the COMBI and MULTI COMBI algorithms.

The results produced by FCOMBI algorithm are PSNR of 102.922251 and MSE of 0.031947. These values showed that the signal enhancement done with the FCOMBI algorithm is better. The same is also confirmed when the results obtained are compared against the signal separation and enhancement techniques suggested by M.
Ahmadi et al. The authors in this discussion used polynomial networks for separation of ECG signals. The proposed algorithm also preserves the information in the signal better than the other algorithms.

The FCOMBI signal separation method followed in the proposed work is based on the unresolved components in the output of EFCIA. With this effective fetal ECG separation is done. The PSNR and MSE obtained with this method are 102.922251 and 0.031947 respectively. This method of signal separation is more effective than the method suggested by Maha Shadaydeh et al. The algorithm suggested by the authors used non-linear relation between the thoracic signal and abdominal signal. Both of these algorithms can be applied over real-time ECG signals for analysis.

The proposed algorithm classifies the fetal heart disorders into seven classes compared to the algorithm developed by Matonia.A et al. which could identify only hypoxia type disorders. Both these algorithms use the fetal ECG signal segregated from the abdominal signal for the study.

The FCOMBI algorithm is a simple noise removal and fetal ECG extraction procedure compared to the algorithm proposed by Mohamad Ayat et al. The latter algorithm uses Savitzky-golay smoothing filter for noise removal and polynomial networks for fetal ECG signal segregation. Both these algorithms showed similar performance in fetal ECG signal separation with both real-time abdominal signal and synthetic ECG signals.

Mohammad Niknazar et al. identified the QRS complex in fetal ECG signals using three-way tensor decomposition methods. It is a known fact that the abdominal ECG signal was mixed up with maternal ECG signal and fetal ECG signal. Three-way tensor decomposition method was a BSS technique to separate fetal ECG signal from the abdominal ECG. In this method, the R-peaks in the maternal signal were identified using the quasi-periodic nature of the ECG signal. The maternal ECG signals were mapped onto a three-dimensional array. The tensor will decompose these matrixes and subtract the maternal components from the abdominal ECG. The results yielded were the fetal ECG components. The developed algorithm was tested with the set of Physionet 2013 database. The algorithm produced an average score of 1514.59 and 57.01 with event 4 and event 5 respectively.

The proposed algorithm diagnoses seven types of fetal heart disorders and it has an effective noise elimination technique. Moreover, it is also independent of the
placement and number of electrodes. This algorithm provides the answer to the
research work carried out by Niyan Marchon et al. The author attempted to study the
impact of placement of electrodes, power line interference, etc. on the analysis of fetal
ECG signals.

The proposed method is a semi-automated method of fetal ECG signal analysis
compared to the automated method proposed by Peter Van Leeuwen et al. This
automated algorithm identifies the variations in the RR interval more accurately. Even
though this algorithm is an automated process, it can be applied only over the signal
acquired using high quality fetal magneto electrocardiographic devices. On the other
hand, even though the proposed algorithm is a semi-automated method, it is
independent of the quality of the signal produced by the ECG device.

The tool developed by R. Rasu et al. aids in the analysis of fetal heart
abnormalities. The tool was developed using FPGA. This tool acts as an effective fetal
heart monitoring tool. But the waveform furnished by this tool needs manual analysis
for diagnosing the type of heart disorders associated with the fetal ECG. Whereas the
proposed algorithm used does not need any manual analysis for diagnosing the type of
disorders associated with the fetal heart, this makes the advantage of the proposed
algorithm compared to the other algorithms under discussion.

The FCOMBI method used for fetal ECG signal separation is a simpler process
compared to the algorithm suggested by Ravindra Kumar S et al. The algorithm
suggested by the author used correlation, subtraction, matched filtering, linear
regression and ICA techniques for fetal ECG signal extraction. This algorithm can be
used for analysis of signals acquired with only minimum number of electrodes. This
drawback is also eliminated in the proposed algorithm, which can be applied for the
analysis of fetal ECG signal irrespective of the number of electrodes used for signal
acquisition.

The proposed FCOMBI BSS algorithm is much simpler over the BSS
algorithm developed by Reza Sameniet al. The latter algorithm was depending upon
the Eigen value decomposition methods. The authors also attempted to make use of
dipole vector theory to extract fetal ECG components from multichannel ECG signals.
The advantage of this algorithm is that it can perform compression of ECG signals in
addition to extraction of fetal ECG signals. This compression cannot be done with the
proposed algorithm.
The results produced by the proposed algorithm are similar to the results produced by Rik Vulligs et al. which used linear prediction and dynamic segmentation methods for the separation of ECG signals. Though this algorithm has an advantage of differentiating the ECG signal acquired between the fetus as rest and during movement over the proposed algorithm, the method of analysis and segregation of fetal ECG is complex. This is the disadvantage of this system over the proposed system.

The non-linear analysis method proposed by Ritcher .M could segregate fetal ECG signal only from single electrodes. For more than one electrode, the algorithm cannot be applied whereas the proposed algorithm can be used for analysis of ECG signals irrespective of the number of electrodes used for signal acquisition. The performance of the proposed algorithm in noise reduction process is also much satisfactory over the other algorithms.

The ICA techniques for ECG signal separation suggested by Ruben Martin-Clemente et al. reduced the preprocessing procedures to be done on the abdominal ECG signals. The same feature is also produced by the proposed algorithm, which uses the FIR and PCA technique. Both the algorithms took equal computation time in signal analysis.

This proposed algorithm has good signal to noise ratio compared to the algorithm developed by Shahrzad Kharabian et al. which uses hybrid techniques for fetal ECG signal separation from the abdominal signal. The FCOMBI technique used in the proposed algorithm is much simpler compared to the Hilbert transformation technique used in the other algorithms. The results obtained with filtering and enhancement show that the proposed algorithm is superior to the other algorithms under discussion.

The algorithm developed by Subhashini et al. produced high quality fetal ECG signals. This method used the difference between the abdominal and maternal components for fetal ECG signal separation. This is done with the aid of ANFIS. This method of analysis is complex compared to the proposed algorithm. The FCOMBI algorithm used for fetal ECG signal segregation is a simpler process compared to the others. Moreover, the FCOMBI algorithm also produced high quality fetal ECG signal similar to the other algorithms under discussion.

This algorithm is also a novel BSS algorithm. This algorithm produced high signal to noise ratio compared to other popular algorithms such as ICA, FASTICA, JADE and Joint BSS algorithms such as MCCA, SOBI, JBSS_SOS, and
JBSS_CUM4. This is confirmed by making a comparison of results produced by the Sugumaretn et al. with the proposed algorithm.

The physiology-based signal separation technique suggested by Warmerd am et al. performed with the multichannel ECG signals for separating the fetal ECG signals from the maternal components. The algorithm also produced satisfactory signal to noise ratio. The proposed algorithm also performs well with the multichannel ECG recordings. The signal to interference ratio produced by the proposed algorithm is 6.544. This value shows that the signal enhancement done with the proposed algorithm is high compared with the other algorithm under discussion.

The algorithm suggested by Yanjun Zeng et al. used recursive least square techniques and adaptive noise cancellation techniques for the removal of maternal components in the fetal ECG signals. The results produced by this algorithm are satisfactory. The FCOMBI algorithm used for signal separation in the proposed algorithm also produced much satisfactory results. Both these algorithms can be used for the analysis of both real-time and synthetic ECG signals.

The least square algorithm suggested by Yi Shao et al. produced the fetal ECG signals from the signals acquired from the thoracic and abdominal regions. The proposed algorithm can be applied for separation of fetal ECG only with the signals acquired from the abdominal region. Analysis with thoracic signal can be implemented which makes the analysis more effective with the proposed algorithm.

The blind source algorithm proposed by Zarso et al. used higher order statistics for the extraction of fetal ECG signals. This algorithm was a much robust algorithm. The proposed FCOMBI algorithm is also a much robust algorithm. In the case of performance, the proposed algorithm performed well with the signal separation compared with the other algorithms under discussion.

The modified Barros algorithm proposed by Zhi-Lin Zhang et al. does not require prior knowledge for the extraction of fetal ECG signals. The results produced by this algorithm are also satisfactory. The FCOMBI method used in the proposed algorithm also does not need any prior knowledge about the ECG signals. Both these methods show similar performance with fetal ECG signal separation.

Zining Ding et al. proposed an algorithm using SVM for fetal ECG extraction process. The author used three kernel functions such as linear, RBF and polynomial kernel functions for the study. With the study made it is found that linear kernel function fails completely in the suppression of maternal components. RBF kernel
performs better than polynomial kernel function, but it has large computation time compared with the polynomial kernel functions.

![Fig.5.1. Comparison chart for different separation techniques](image)

The Fig.5.1. shows the summary of the results obtained with various signal separation techniques used in this work. The comparison chart shows that the FCOMBI technique has produced high SIR and PSNR rate over the other techniques. Hence the same is used for fetal ECG separation in this work.

### 5.3 NOISE REMOVAL METHODS

The algorithm developed by G. Michaela Ungureanu *et al.* used adaptive filters for the removal of noise from the abdominal signals. This algorithm is able to successfully remove the undesirable harmonics from the real-time and synthetic ECG signals. The proposed algorithm using the combination of FIR and PCA also could remove the undesirable harmonics from the abdominal ECG signals. The advantage of the proposed algorithm is that it has high PSNR values compared to the other algorithms. Moreover, the proposed algorithm preserves the information present in the signal much more effectively than the other algorithms.

The algorithm developed by E. C. Ifeachor *et al.* used intelligent models and fuzzy logic techniques for noise removal in the abdominal ECG signals. The other algorithms developed by the same authors. They used non-linear methods to identify the disorders in the fetal heart. The proposed algorithm uses the combination of FIR and ICA methods for the noise removal in abdominal ECG signals. The quality of signal after noise removal by the proposed method is high compared with the method
followed by the other authors in this discussion. Moreover, the added advantage of the proposed method is that it also defines the type of disorders that are associated with the FHR.

The algorithm developed by Hamid Hassanpour and Amin Parsaei et al. uses Daubechie wavelet transform and Savitzky-Golay smoothing filter for the separation of fetal ECG signal and noise removal in fetal signals respectively. The performance rate produced by the developed algorithm is also satisfactory. This proposed algorithm using FCOMBI and FIR+ICA methods was adopted for fetal ECG separation and produced much better results than the other algorithms under discussion in terms of PSNR values and least MSE. Moreover the signal separation and noise removal processes with the proposed algorithm are simpler than with the other algorithms taken for discussion.

The adaptive filtering technique used for noise removal by Kam.A and Cohen A performed well with abdominal ECG signals. The results produced by the signal showed significant variations in the noise signal that were mixed with the actual signal. The FIR and ICA combinations of noise removal technique used in the proposed algorithm also show this significant difference. The analysis of signal with FIR and ICA is easier than the analysis of signals by adaptive filtering techniques.

The FIR and PCA techniques of noise removal methods used in this proposed work performed well, which produces a PSNR of 102.922251 and MSE of 0.031947. This result is superior to the noise removal methods used by Luis Omar Sarmiento Alvarez et al. The authors made a study with two noise removal techniques such as PCA and JADE-R algorithm. Moreover, the method of noise removal used in the proposed work is also easier compared to the other two methods.

The fetal ECG separation method suggested by Mamun Bin and LbneReaz has high learning rate, low momentum and small initial weights. The authors also developed the tool as the GUI tool. The noise suppression techniques used in this tool is not satisfactory. Due to this, the results obtained with this method are also not consistent. On the other hand, the noise removal techniques used in this proposed work uses the combination of FIR and PCA methods for noise removal. The final classification accuracy achieved with the proposed algorithm is 96.53 %. This shows that effectiveness of noise removal and training methods followed in the developed algorithm.
This proposed algorithm is sensor-independent, i.e. the algorithm can be applied for the analysis of ECG signals acquired from any number of electrodes. This shows the compatibility of this proposed algorithm when compared to the algorithm developed by Mehdi Poursoltani et al. The latter algorithm uses wavelet-based ICA techniques and can be applied for the analysis of ECG signals acquired from two electrodes. The classification results presented by the proposed algorithm are also more compared to those of the other algorithms under discussion.

The proposed algorithm which uses the combination of FIR+PCA for noise removal process has produced a MSE of 0.031947. This value is much less compared to the algorithm developed by Minnan Xu-Wilson et al. which uses spatial filtering technique for noise reduction. The MSE produced by this algorithm is 10.61. The reduced value of MSE in the proposed algorithm shows the effectiveness of the noise reduction procedures adopted in the proposed algorithm.

The algorithm developed using adaptive technique by Soleit E.A et al. removed the noises caused due to various factors. The proposed algorithm also does the same. Even though both these algorithms are effective in noise removal process, the proposed algorithm is simpler compared to the other. On the other hand, the algorithm suggested by the authors can be extended for estimating the heartbeat rate. This factor is not considered in the development of the proposed algorithm.

The algorithm developed by T. K. Padma shri et al. used least square methods for the removal of noise from abdominal ECG recordings. The FIR and PCA combination used for noise removal in the proposed algorithm produced good signal to noise ratio and least MSE values. These values show that the noise removal has been done more efficiently. This noise suppression aids in producing more accurate results.

The combination of Weiner filter method, Recursive Least MSE method and normalized least mean method used by Talha M et al. produced satisfactory results. To improve the optimization, the authors attempted with finite impulse filter, adaptive filters and Genetic algorithms. Though the expected optimization was achieved, the number of iterations needed is more. On the other hand, the proposed algorithm also produced more optimized results. The number of iterations needed for the proposed algorithm is also less. This reduction in the number of iterations reduces the execution time for producing the classification results.

The denoising technique developed by Taralunga.D et al. helps the physicians to analyze the fetal movement and the conditions of the fetal heart with the denoised
signal. In addition, these signals also help to predict the labor and the pre-labor conditions. The denoised signal furnished by the combination of FIR and PCA can be applied only for the classification of fetal ECG disorders. The features discussed in the early algorithm can be implemented in the proposed algorithm. This makes the proposed algorithm more compatible for the analysis of fetal health monitoring.

The algorithm developed by Vennila.M and Sikkandar Mohamed Yacin uses Kalman filters for the suppression of noise in fetal ECG signals. Though this algorithm has an advantage of analyzing the signals that were overlapped with each other, this can be used for the analysis of signals that are acquired only from single electrodes. On the other hand, the proposed algorithm is independent of the number of electrodes. It can be used for the suppression of noise in signals which is acquired from any number of electrodes.

The proposed algorithm is a simple noise signal suppression process compared with the algorithm developed by Vijaya C.K.S et al. Both these algorithms are applied on abdominal signals. The FIR and PCA method are simple compared with the adaptive filter and neuro-fuzzy system method followed for the removal of noise in earlier algorithms. Both these works are developed in MATLAB platform. Promising results are produced by the proposed algorithm over the others.

The Undecimated Wavelet Transform (UWT) and a FFT - IFFT techniques suggested by Viorelonescu et al. for noise suppression in abdominal ECG signals produced useful results. The authors also attempted Undecimated Wavelet Transform (UWT) and a FFT – IFFT for signal enhancement. Though the above techniques produced fruitful results, the method of analysis is complex compared with the proposed algorithm. The FIR and PCA techniques used in the proposed algorithm for noise suppression and signal enhancement is an easier and effective way of analyzing abdominal ECG signal compared to the others.

The projective filtering technique and matched filtering technique suggested by Winnie Rachel Cherian et al. act as an effective noise removal algorithm for suppression of noise in fetal ECG signals. The same is done by the FIR and PCA combination in the proposed algorithm. The advantage of the proposed algorithm is that it can be applied for noise removal in multichannel ECG recordings whereas the earlier algorithm is applicable only for removal of noise acquired from single channel ECG recordings.
The second-order statistics technique suggested by Yalan Ye et al. performed as an effective noise removal algorithm. The estimation of cost function is a challenging task in this algorithm. The proposed algorithm does not have any of these challenging tasks. The efficiency of both these algorithms is satisfactory.

The convergence rate produced by the proposed algorithm is also the same as the convergence rate produced by the algorithm of Yaping Ma et al. This algorithm uses fuzzy logic and artificial neural networks for the separation of fetal ECG signals. The difference between the abdominal signal and the maternal signal produced the fetal signal in this technique. Both these algorithms are applicable for the analysis of signals acquired from multichannel ECG device. The noise suppression performed with the combination of FIR and PCA in the proposed algorithm is also promising compared to the Volterra filter and neural network suggested by the same author.

The PSNR value produced by the FIR and PCA combination in this proposed method for noise removal and signal enhancement is 102.922251. This value shows the effectiveness of the FIR and PCA combination in signal enhancement. This enhancement done on the signal is high compared to the algorithm suggested by Paolo Melillo et al. The latter algorithm uses spatio-temporal filtering for the same. This algorithm has a drawback with the calculation of weighting coefficients, whereas the proposed algorithm does not need any weighting coefficients for signal enhancement.

The proposed algorithm provides the solution to the problem identified by Rajesh A.V et al. in their study. The study made by the authors has concluded that the fetal ECG signal has low signal to noise ratio. This problem is solved by the fetal ECG extraction and signal enhancement techniques used in the proposed system. The combination of FIR and PCA for signal filtering and enhancement used in the proposed system has produced a PSNR of 102.922251. This shows the strength of the signal enhancement done with the proposed method.

5.4 CLASSIFICATION

The algorithm developed by Foresta F.La et al. used ICA and wavelet decomposition techniques to analyze the cardiac pathologies. The proposed algorithm used morphological feature extraction technique and Naive Bayes algorithm to diagnose the various fetal heart disorders. The advantage of the proposed method over the other method is that the accuracy, specificity and sensitivity of the proposed algorithm are higher compared to the other algorithms under discussion. Moreover, the proposed
algorithm identifies five major fetal heart disorders compared with the other algorithms.

The automated algorithm proposed by Ahsan H Khandoker et al. identifies the normal and abnormal conditions of the fetal heart. The Iso-volumic contraction time and Iso-volumic relaxation time are used to define the normal and abnormal conditions of the heart. The coefficient of variation observed with this method 0.01 which defines the consistency of this algorithm. Though this method has many advantages, the major drawback with this method is that it does not give any information regarding the type of fetal disorders that occur in the fetal heart. On the other hand, with the proposed algorithm seven kinds of heart disorders can be found. This is the major advantage of this proposed algorithm over the other algorithms taken for the study.

The algorithm proposed by Arby. P et al. uses multi-fractal analysis method for continuous monitoring of FHR. This heart rate monitoring aids in the diagnosis of asphyxia. In the proposed method, morphological features are used to analyze the FHR. This analysis aids in identifying seven different cases of heart disorders such as Normal Fetal ECG signal, Atrial Fibrillation, Wolff-Parkinson white syndrome, First degree block, Paced Signal, Ventricular tachycardia, and Idioventricular Rhythm. This becomes the advantage of the proposed algorithm over the other algorithms taken for discussion.

The algorithm proposed by Giulia Da Poian et al. also uses FCOMBI algorithm for the separation of fetal ECG signals. The classification of signals by naive Bayes classifier also yields an accuracy of 92.5 %. The proposed algorithm also uses the same combination for diagnosing the fetal heart disorders. But the accuracy of this proposed algorithm is higher compared to the earlier ones. This increase in the classification rate with the same combination of separation and classification method is due to the noise filtering technique used in both the combinations. As the noise filtering is done effectively in the proposed algorithm, this algorithm has achieved higher classification rate.

The algorithm proposed by Greene. K et al. uses the negative PR and RR intervals for identifying heart disorders. The analysis made with this algorithm provides the details regarding the cardiac failures. The intra-heart structures and relations are also furnished by this algorithm, whereas the proposed algorithm will furnish information only regarding the various types of heart disorders, but it does not
provide any information regarding the intra-structures of the heart, which is a drawback of the proposed algorithm.

The algorithm proposed by Ismet Sahin et al. used discrete Fourier transform for the estimation of fundamental components in ECG waveforms. This aids in the identification of two types of heart disorders such as hypoxia and academia. The performance of the proposed algorithm is also satisfactory. The proposed algorithm has many advantages over this algorithm. The proposed algorithm identifies five types of heart disorders. Moreover, the accuracy of the proposed algorithm is 96.53%. This accuracy rate is high compared to the other algorithm taken for the study.

The algorithm developed by János Szalai et al. used fast ICA technique for the estimation of FHR. This algorithm highly depends upon the amplitude of the extracted fetal ECG signal in estimating the fetal heartbeat rate, which further aids in the analysis of fetal heart disorders. The proposed algorithm also aids in the diagnosis of fetal heart disorders. The advantage of the proposed algorithm is that it does not depend on the amplitude of the fetal ECG signals. This is because the morphological feature extraction technique used in this work aids in easy analysis of fetal ECG signals irrespective of the amplitude of the signals.

The proposed algorithm has much higher accuracy of 96.53% as compared to the tool developed by Kalarin J et al. which has an accuracy of 93%. Both of these could differentiate the P-wave, QRS complex and T-wave in fetal ECG. The accuracy of the proposed algorithm is high. This is the advantage of the proposed algorithm over the other.

The signal analysis made by Khandoker AH et al. on Doppler signals could successfully differentiate the normal and the abnormal fetus. SVM classification algorithm was used in this work. The results obtained were also satisfactory. On the other hand, the results produced by SVMs with the ECG signals in the proposed work are not satisfactory. In the proposed work, satisfactory results are produced by the Naive Bayes Classifier.

The accuracy produced by the HDNB classifier in the proposed work is 96.53%. This accuracy is much higher compared to the algorithm suggested by Luis Omar Sarmiento Alvarez et al. The authors used COMBI, MULTI-COMBI and JADE methods for fetal ECG signal separation from the maternal ECG signal. The same signal separation methods are tried in the proposed work. But the FCOMI method
produced effective signal separation than the other methods. So, improvement in the accuracy is observed in the proposed work compared to the others.

The proposed algorithm identifies instantaneous fetal heart disorders when compared to the algorithm proposed by M. A. Pena C et al. The algorithms suggested by the authors rely on the statistical comparison between the abdominal and RR recordings. An error in the statistical parameter estimation may cause an error in the results. In the proposed algorithm, the results are produced based on the initial training done on the classifier. The results produced with this approach will be error-free over the other methods under discussion.

The proposed algorithm has high specificity, sensitivity and accuracy compared to the algorithm proposed by Michil Rooijakkers et al. which used ultrasound signals and wide spectrum techniques for monitoring the fetal health issues. Even though this algorithm has produced low classification results, it can also be used to monitor the fetal movement which cannot be done with the proposed algorithm. This drawback in the proposed algorithm can be rectified by the further development of this algorithm.

The proposed algorithm implemented the suggestions given by Saladi.S.V.K.K.Anoop et al. The authors suggested that noise-free signals produce much accurate results than the signals which are mixed up with noise. The author also discussed the importance of analyzing the QRS complex for the diagnosis of fetal heart disorders. This proposed work has considerably suppressed the noise parameters in the abdominal ECG signal. This can be confirmed with the results produced by FIR and PCA combination. The classification results are done based on the analysis of QRS complex. The classification accuracy produced by this algorithm with QRS complex analysis is also satisfactory.

The wavelet transform method of analysis on RR interval made by Shashi Kala Nagarkoti et al. for diagnosing fetal ECG disorders produced sensitivity and positive predictive values of 97.88 % and 97.06 % respectively. This sensitivity and specificity values are less compared to the proposed algorithm. Moreover, the proposed algorithm performed the classification based on both RR interval and QRS complex analysis. The results showed that the proposed algorithm is more accurate than the other algorithm taken for the comparison.

The algorithm developed by Varanini M et al. used baseline removal and power line interference cancellation for removing noise in abdominal ECG signals.
The enhancement in this work was done with ICA technique. This algorithm produced an accuracy and sensitivity of 99.2 % and 99.4 % respectively. The proposed algorithm which uses FIR and PCA combination performed better noise removal and enhancement compared with the earlier algorithm. Moreover, the classification accuracy and sensitivity produced by the proposed algorithm is also high compared to the others. These parameters make the proposed algorithm more reliable over the others.

The algorithm developed by PiotrPozimskiet al. used the difference between the RR interval peaks for defining the normal and abnormal conditions of the fetal heart. Even though the test score is satisfactory, this algorithm is not able to define the type of disorder in fetal heart. The proposed algorithm also has comparatively good classification rate. In addition to defining the normal and abnormal conditions, it also defines the type of disorder associated with the corresponding fetal heart.

The efficiency of the hardware developed by Shuang Song et al. for fetal ECG analysis and monitoring is 90 %. This accuracy is less compared to the proposed algorithm. Moreover, the earlier algorithm is a hardware tool which cannot be modified easily for future requirements. On the other hand, the proposed algorithm is a software tool which can be modified easily as per future requirements.

The HDNB classifier is compared with different classifier and the resulting parameters such as sensitivity, specificity, accuracy and precision are listed in the below Table 5.1.

<table>
<thead>
<tr>
<th></th>
<th>Feed forward NN</th>
<th>Multi-class SVM</th>
<th>Naïve Bayes (Normal Distribution)</th>
<th>Naïve Bayes (Multivariate Distribution)</th>
<th>Naïve Bayes (Multinomial Distribution)</th>
<th>HDNB classifier</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitivity</td>
<td>75.3</td>
<td>76.83</td>
<td>83.56</td>
<td>72.08</td>
<td>55.69</td>
<td><strong>89.56</strong></td>
</tr>
<tr>
<td>Specificity</td>
<td>76.7</td>
<td>95.37</td>
<td>96.51</td>
<td>94.60</td>
<td>91.80</td>
<td><strong>97.54</strong></td>
</tr>
<tr>
<td>Precision</td>
<td>65.8</td>
<td>76.94</td>
<td>82.05</td>
<td>73.18</td>
<td>53.06</td>
<td><strong>87.98</strong></td>
</tr>
<tr>
<td>Accuracy</td>
<td>77.1</td>
<td>92.94</td>
<td>94.81</td>
<td>91.71</td>
<td>86.85</td>
<td><strong>96.53</strong></td>
</tr>
</tbody>
</table>
Fig. 5.2 Comparison result for Classifiers

From Fig. 5.2, it is concluded that the proposed algorithm for classification of fetal ECG disorders is much simple and superior to the other algorithms developed by the researchers. The specificity and sensitivity rates show the consistency of the diagnosing rate made by the proposed algorithm. The accuracy produced by the developed algorithm shows the accuracy of the classification of fetal disorders from the ECG signal.

5.5 MAJOR NOVELTIES OF THE RESEARCH WORK

From the results and discussion the following are the major novelties identified with this research work.

- Diagnose more class of fetal heart disorders
- Improved specificity and sensitivity over the existing work
- Classification with high accuracy over the existing algorithms
- Effective fetal ECG separation technique is defined.
- Efficient noise removal technique is defined.

The statistical analysis made for the above parameters for the proposed algorithm over the other algorithm reveals that this algorithm is unique over the existing algorithms.