The Ciência & Engenharia - Science & Engineering Journal
ISSN: 0103-944X
Volume 10 Issue 1, 2022
pp: 233 - 239

Fetal ECG Extraction by Principal Component Analysis

Tushar Debnath [1], Kumar Amitabh [2]
[1]Faculty, Electronics And Communication Engg, Nielit Agartala, India,
tushar.grenoble19@outlook.com
[2]Senior Technical Officer, Nielit Agartala, India
amitabh.mcit@gmail.com

Abstract
Fetal ECG plays a very important role in determining the growth of the baby inside the mother's body. The focus is on isolating the ECG signal of the fetus from that of the mother. The step is to understand the five waves of the signal and learn about its main functions. Then an algorithm named R-Peak Detection is applied and further to remove the noises which can interfere with the main signal a series of filters are used. Further a Component Analysis πCA is applied in order to extract the signals of the fetus and the results are discussed.

Keywords: ECG signal, R-Peak Detection, πCA, ICA, QRS Signal, T Signal, Filtering.

1. Introduction

Signal Processing has a vast field of applications which is spread even in medical field. One of such applications is the extraction of fetus signal to check whether the baby that is growing inside the mother is normal or not. As the baby is inside the mother's womb, the signal that is extracted is the summation of both the mother's ECG and the fetus's ECG. In order to extract and separate the ECG signal from the mother's and the fetus, a series of processing stages are involved which is dealt in this session. In the first part, the basic of ECG signals is covered and the second part covers the different processing stages that is filters applied to the signal in order to detected the main peak, which is also referred as R-Peak Detection. In the third part the πCA algorithm is applied in order to separate the mother's ECG from the fetus ECG.

2. Literature Survey

Electro-Cardiogram or ECG signals are non-stationary and providing us the nature of human's heartbeat. The nature of the heartbeat is first analyzed and then classified for detecting different diseases that is threatening to life. Further we use different optimizers to find out the most possible features during an ECG with greater accuracy.[3][1] The activity of a person's heart can be analyzed through the extraction of features. This plays a very important connection during monitoring the fetus of a mother during pregnancy. Fetal ECG is one of the vital applications in this area. The Fetal Heart Rate is a very low frequency signal ranging from 1.3 to 3.5 Hz and so these signals appear to be closely overlapped. Due to this reason a number of algorithms were developed to extract the heart rate signal with better quality and diagnose the accurate fetal signal and also reduce noise.[2]

The Ciência & Engenharia - Science & Engineering Journal
ISSN: 0103-944X
Volume 10 Issue 1, 2022
pp: 233 - 239

Now Fetal ECG signals and normal heartbeat signals can only be separated by a very popular process named as Blind Source Separation Method. As separation of two or more heartbeat signals should be done to get the exact fetus pulse so for a long time Independent type component analysis (ICA) is used to filter out the original required signal.[4] *Reza et al* proposed in their work that independent component analysis is based on maximizing some nonlinear criterions and on the other hand the ECG signals are very rich in information. Also, ECG signals are periodic on nature so periodicity is the right criteria for proper detection. Source separation technique has been tried a lot for this purpose in the recent years.[6] Also it was proposed earlier that PCA is one of the better expansions of source separation method [5]. It depends on the Eigenvalue decomposition method. As fetal data is a multivariate data so to analyze, PCA is the most suitable one as it depends on the singular value decomposition technique. Here the most important information is extracted as an orthogonal component and denoted as principal component.[7] So we have approached with this technique to access the fetal information from the body of a mother.

3. Electro-Cardiogram (ECG)

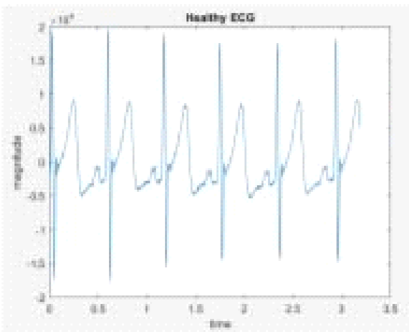
Electro-Cardiogram is the test used in the medical field to record the nature of the heart. The heart pumps blood continuously, thus the signal from the ECG is a periodic one. There are 5 signals that are found in ECG:

• P-Signal: This is produced from the depolarization of the atrium

• QRS Signal: The main peak that is observed, produced due to the depolarization of the septum

• T signal, which is produced from the re-polarization of the ventricle.

The first step is to analyze the ECG signal and its frequency response. The ECG signal and its spectrum is shown in Figure 1. In order to understand precisely the variation of these frequencies with respect to time, a spectrogram will be useful. The spectrogram of the above signal is shown in Figure 2. A Hanning window was chosen with a small range of the window to analyze the behavior of frequency with respect to time.



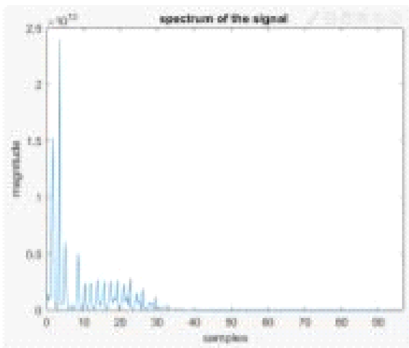


Figure 1 - The ECG with 5 signals (left) and the frequency response/ spectrum of the signal (right). The first 10 samples (approx.) has relatively high frequency content in the signal. The sampling frequency selected here is 1Khz.

The Ciência & Engenharia - Science & Engineering Journal
ISSN: 0103-944X
Volume 10 Issue 1, 2022
pp: 233 - 239

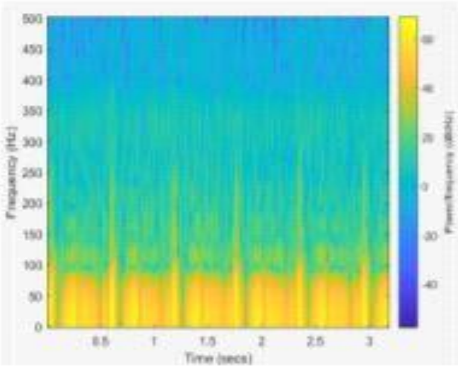


Figure 2- The spectrogram of the frequency components. This is just the short time Fourier transform of the signal.

4. R-Peak Detection

R-peak detection technique is very crucial in determining the ECG signal components. Wavelet Multiresolution analysis is used to enhance the signal and then mirror image is found for getting positive R-peaks from negative ones. The proposed algorithm gives more than 90 percent accuracy in most cases of ECG analysis.[8] In the previous section, the basic ECG signal is analyzed. The main object is to extract the QRS component peak of ECG signal. A simple detection of the QRS component isn't possible. This is because of several factors like noises due to muscle and even due to the instruments, also the baseline errors. Thus, various filtering stages are applied to it in order to clear these external parameters.

4.1 Filtering Stage

The QRS peak gives important information in the field of Bio-Medical field and any minor mistake can have very disastrous consequences. Thus, a proper filter design is to be corporated.

4.1.1 Low Pass Filtering

In the first case, the low pass filter is used to filter the noise and external parameter in the S signal. The design is given by:

where N is the number of intervals taken. The value of N for the low pass filter is 6.

4.1.2 High Pass Filtering

Similarly for the high pass filter the design is given by: . In this case the number of tapping are equal to 32.

4.1.3 Derivative Filter

Now, once the signal is filtered, free of the noises and the baseline errors. The derivative of the signal is taken. This is based to the fact that the slope of the QRS is steep.

The Ciência & Engenharia - Science & Engineering Journal
ISSN: 0103-944X
Volume 10 Issue 1, 2022
pp: 233 - 239

4.1.4 Square Filter

The derivative filter has some part of the signal in the negative side. To shift the signal all in the positive side, the signal is squared.

4.1.5 Moving Integral Window

The signal now is all positive. But the peaks have a sharp descent at the peaks. The Moving integral window avoids such sharp descent of the peak.

The corresponding stages of the filters incorporated in the analysis is shown in Figure 3. Similarly with the number of beats that are synchronized with the QRS signal.

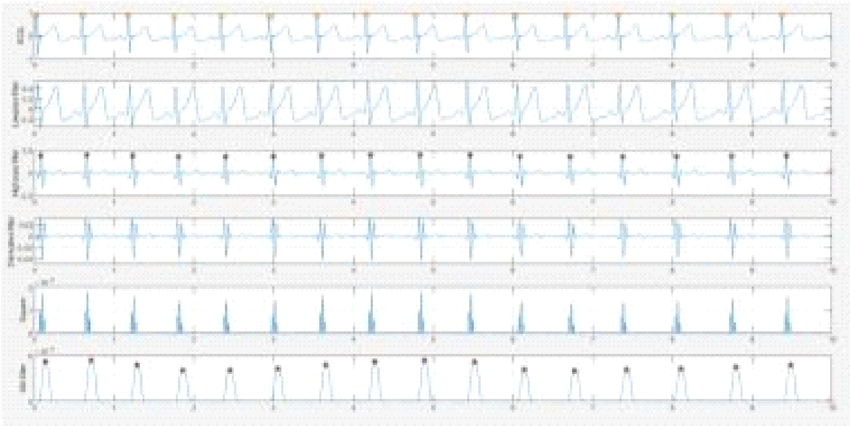


Figure 3: The different filtering stages used in the analysis. The original unfiltered ECG signal (top), Low pass filtered signal (second from top), high pass filtered signal (third from top), derivative filter (third from bottom), squared filter (second from bottom) and the final Moving Integral Window Filter (bottom).

5. Fetal Ecg Extraction

In this section we will use several algorithms to extract a fetal ECG from the ECG of its mother. This is a delicate exercise, because the sensors record the mother ECG that is much more intense, and an important noise due to the body activity, so the fetal ECG is almost invisible. The main algorithm that will be used in this section is the Periodic Component Analyses (πCA) algorithm, which enable to extract almost periodical components, that are more likely to show the main features of the input signals. We will start by performing a decomposition of the electrocardiogram using the Periodic Component Analysis, a method who's the aim is to separate the" most periodic" linear mixture from the recorded multi-channel ECG. We first apply a high-pass filter as preprocessing, to remove the baseline of the signal, due to body activity and considered as noise. By observing the DSP of the signal, we note that it contains important low frequency components under 15 Hz. So, we choose a cutoff frequency of 20 Hz, to put the light on the QRS complex of the ECG of the mother and the fetus, corresponding to higher frequencies.

The Ciência & Engenharia - Science & Engineering Journal
ISSN: 0103-944X
Volume 10 Issue 1, 2022
pp: 233 - 239

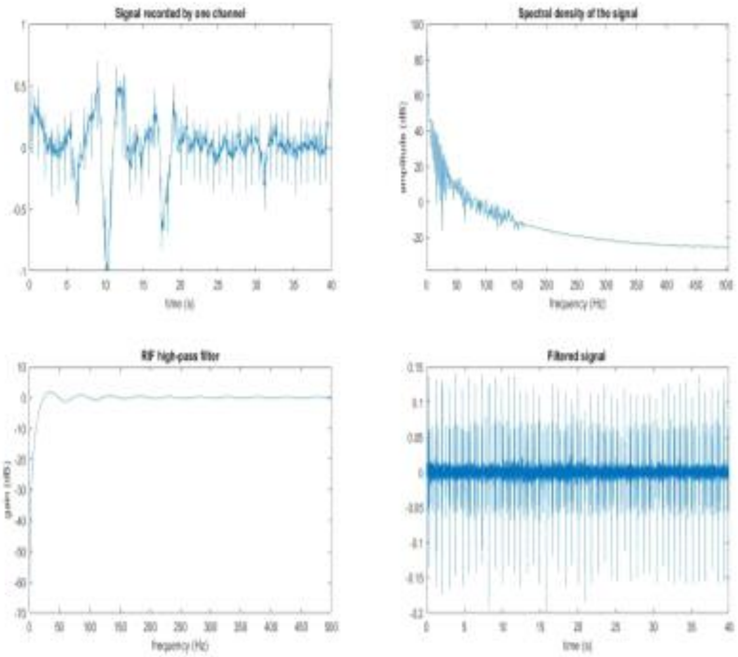


Figure 5: From left to right, and top to bottom: the signal recorded by one channel, its spectral density, the gain of the applied filter, and the resulting signal.

It can be observed that the result is satisfying. The baseline has been removed, and we can discern the highest peaks, corresponding to the mother ECG, and some smaller peaks, that may correspond to the fetal ECG.

Then we apply the algorithm of QRS complex detection to the resulting filter, to identify the samples' indexes

corresponding to the R peaks of the mother ECG. Those peaks will define the periods that will be used for the CA

Algorithm.

Indeed, the CA performs the decomposition of a pseudo periodic signal. Thanks to the R peaks detected, we can delimit each period of the signal, and extract the principal components with respect to the periods.

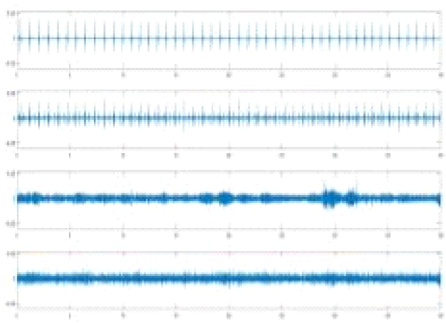


Figure 6: Most Periodical components extracted by the CA algorithm.

The Ciência & Engenharia - Science & Engineering Journal
ISSN: 0103-944X
Volume 10 Issue 1, 2022
pp: 233 - 239

The results show that the first component corresponds to the ECG of the mother, and the second component presents ECG both of the mother and the fetus. Nevertheless, none of the components presents only the fetal ECG. The cause is that the periods used for the algorithm are based on the mother R peaks, so the component are highly related to the ECG of the mother.

We also shortly tried to implement the CA algorithm with the periods corresponding to the fetal R peak to extract the fetal ECG. It was remarked that our algorithm of detection of R peaks detected also the peak of the fetal ECG after applying the band-pass filter, but not after the use of the derivative and moving integral window filters. So, by removing the indexes of mother R peaks to the indexes of mother and fetus R peaks. I could think that the fetal ECG extraction would work. Nonetheless, the detected R peaks corresponding either to the mother and fetus ECG have been removed, so the results were distorted and not conclusive. We also applied the Principal Component Analysis (PCA) and Independent Component Analysis (ICA) algorithms to compare the different results.

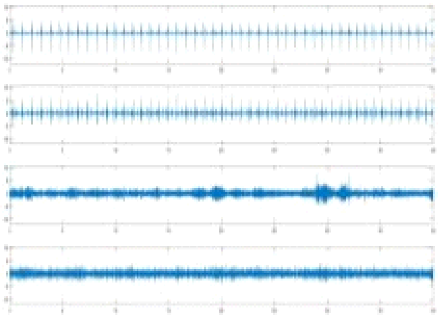


Figure 7: Result of the ICA Algorithm

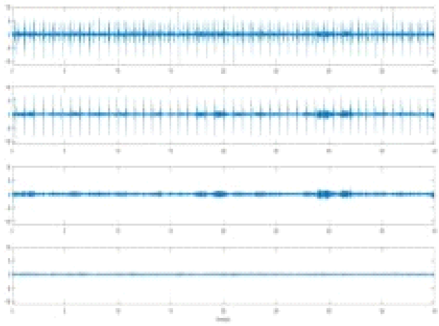


Figure 8: Result of the PCA algorithm.

We can note that the ICA and PCA algorithm both succeed on extracting the ECG of the mother. Nonetheless, we can note that the PCA algorithm returns the ECG of the mother without removing all the noise of the original signals. The independence between the noise and the cardiac activity enables the ICA to extract the mother's R peak with the same quality than the πCA algorithm using the almost periodic information of the signals.

Concerning the fetal hearth beats, the three methods do not isolate the R peaks corresponding to the fetus in one component. The πCA and PCA methods seem to give back one component where we can visually identify R peaks corresponding to the fetal ECG but there still are prints corresponding to the mother R peaks.

6. Conclusion

Finally, this whole work was an overview of signal processing methods used for the analysis of an electrocardiogram. At first, we combined three filters, one band-pass, one derivative and one moving integral window, to denoise the electrocardiogram signal and locate the QRS complex of the hearth beats. We also remarked the importance of using linear filters to get a

The Ciência & Engenharia - Science & Engineering Journal
ISSN: 0103-944X
Volume 10 Issue 1, 2022
pp: 233 - 239

constant delay between the original and filtered signals without any temporal distortion. This constraint of constant delay was then used for the extraction of the ECG of a fetus, from the ECG of its mother, with sensors placed to the level of the mother's abdomen. Indeed, we applied the πCA method, that consists in extracting the" most periodic" mixtures of the electrocardiogram, with respect to the period defined by the locations of the QRS complex. This method, that worked well to isolate the mother's QRS complex from the signal, was unfortunately not sufficient in our case to extract the QRS complex corresponding to the fetal ECG.

References

[1] Kass, R.E. and Clancy, C.E. (2005) 'Basis and Treatment of Cardiac Arrhythmias, Vol. 171, pp. 1–40, Springer Science & Business Media, Springer-Verlag, Berlin Heidelberg.

[2] M.A Hasan, M. B. I. Reaz, et al., "Detection and Processing Techniques of FECG Signal for Fetal Monitoring", Biological Procedures Online, vol. 11(1), pp. 263-295. March 2009. ISSN: 1480-9222

[3] ECG signals classification: a review by Essam H. Houssein*, Moataz Kilany and Aboul Ella Hassanien Int. J. Intelligent Engineering Informatics, Vol. 5, No. 4, 2017

[4] Separation Of Maternal And Fetal ECG Signals From The Mixed Source Signal Using FASTICA Jasper Raj Immanuel.Ja , Prabhu.Va , Jane Christopheraj.Va , Sugumar.Da , Dr.Vanathi. P.T.b , a* Procedia Engineering 30 (2012) 356 – 363

[5] Multichannel Electrocardiogram Decomposition Using Periodic Component Analysis Reza Sameni*, Christian Jutten, and Mohammad B. Shamsollahi IEEE TRANSACTIONS ON BIOMEDICAL ENGINEERING, VOL. 55, NO. 8, AUGUST 2008

[6] M. G. Jafari, W. Wang, J. A. Chambers, T. Hoya, and A. Cichocki, "Sequential blind source separation based exclusively on second-order statistics developed for a class of periodic signals," IEEE Trans. Signal Process., vol. 54, no. 3, pp. 1028–1040, Mar. 2006.

[7] Multivariate Statistical Data Analysis- Principal Component Analysis (PCA) Sidharth Prasad Mishra* , Uttam Sarkar, Subhash Taraphder, Sanjay Datta, Devi Prasanna Swain1 , Reshma Saikhom, Sasmita Panda2 and Menalsh Laishram International Journal of Livestock Research eISSN : 2277-1964 NAAS Score -5.36

[8] An Adaptive and Time-Efficient ECG R-Peak Detection Algorithm Qin Qin, Jianqing Li, Yinggao Yue, and Chengyu Liu Journal of Healthcare Engineering Volume 2017, Article ID 5980541, 14 pages