Journal of Engineering and Applied Sciences
MEDWELL PUBLICATIONS SINCE 2000

Fetal Electrocardiogram Separation Based on Single-Channel by Using Wavelet and Non-Negative Matrix Factorization NMF

Ziani Said and Youssef El Hassouani
Départment de Physique, Faculté des Sciences et Techniques, Energies Nouvelles et Ingénierie des Matériaux (ENIM), Moulay Ismail University of Meknes, Errachidia, Morocco

Key words: Blind source separation, fetal electrocardiogram, continuous wavelet, transform CWT, non-negative matrix, factorization

Corresponding Author:
Ziani Said
Départment de Physique, Faculté des Sciences et Techniques, Energies Nouvelles et Ingénierie des Matériaux (ENIM), Moulay Ismail University of Meknes, Errachidia, Morocco

Page No.: 3581-3585
Volume: 15, Issue 21, 2020
ISSN: 1816-949x
Journal of Engineering and Applied Sciences

Abstract: The present study aims to validate a new approach for blind source separation of fetal electrocardiogram signal FECG and maternal electrocardiogram signal MECG when given only a single channel recording. Most studies have only focused on statistical methods which impose several conditions on the sources and this is not always obvious. The proposed method by combining continuous wavelet transform CWT and non-negative matrix factorization NMF, allows the extraction of the FECG signal with a greater characterization of the QRS complex. This technique can be illustrated by means of a real-life example.

INTRODUCTION

In developed countries, cardiovascular disease tends to become one of the leading causes of maternal mortality. The main etiologies are myocardial infarction, aortic dissection and cardiomyopathies. However, pre-existing maternal heart disease such as congenital heart disease is more frequently encountered and may be associated with significant maternal and perinatal morbidity. This review recalls the hemodynamic modifications due to pregnancy, proposes a stratification of the cardiac risk according to the cardiopathies preexisting with the pregnancy and discusses the monitoring and the overall management of these patients. An electrocardiogram or ECG is a common medical exam to record cardiac activity. It is based on the measurement of electric currents flowing through the organ with each of its contractions. Monitoring the baby's heart with Electrocardiography (ECG) and Cardiotocography (CTG) during labor provides moderate help for mothers and babies when continuous monitoring is required. Strong uterine contractions during labor reduce the flow of maternal blood to the placenta. The umbilical cord can also be compressed during labor, especially if the membranes rupture. Usually the baby has enough reserve to support this effect but some may be suffering. Electronic heart rate monitoring may be suggested if doctors believe the baby may be hypoxic. Two different monitoring methods can be used. CTG measures the baby's heart rate and the mother's uterine contractions. An ECG measures the electrical activity of the heart and the profile of heartbeat. This implies that an electrode is inserted into the mother's cervix and attached to the baby's head. Source separation problems arise when a number of sources emit signals that mix and propagate to one or more sensors. The objective is to identify the underlying source signals based on measurements of the mixed sources. This study deals with the underdetermined problem of source separation when the mixed signals are recorded using only a single sensor. The Electrocardiogram (ECG) signal may provide useful information about the fetus' heart condition for detecting the fetus at risk of damage or death in the uterus. Ziani and co-workers are the founders of the principle of the blind source separation based on the time-scale image[1-7]. In this research, we propose a new algorithm that allows the extraction of FECG signal by combining CWT, NMF and ICWT methods.

Theoretical background

Continuous Wavelet Transform (CWT)

The wavelet transforms: The wavelet transform of a continuous signal is defined as[8]:

$$T(a,b)=\frac{1}{\sqrt{a}}\int_{-\infty}^{+\infty}x(t)\Psi^*\left(\frac{t-b}{a}\right)dt \quad (1)$$

This equation contains both dilated and translated wavelet (t-b/a) and the x(t) signal. The normalized wavelet is often written more compactly as:

$$\Psi_{a,b}=\frac{1}{\sqrt{a}}\Psi\left(\frac{t-b}{a}\right) \quad (2)$$

The signal energy: At a specific scale a and location b the relative contribution of the signal energy is given by the two-dimensional wavelet energy density function:

$$€\,(a, b) = |T\,(a, b)|^2 \quad (3)$$

A plot of is known as a scalogram or times-scales image. Inverse Continuous Wavelet Transforms (ICWT):

$$x(t)=\frac{1}{N}\int_{-\infty}^{+\infty}\int_{0}^{\infty}T(a,b)\Psi_{a,b}(t)\frac{dadb}{a^2} \quad (4)$$

This allows the original signal to be recovered from its wavelet transform by integrating over all scales a and location b. It should be noted that (Eq. 7) is the basic mathematical tool used in the rest of this study.

Non-negative matrix factorization

Definition: Non-negative Matrix Factorization (NMF) is a general method of matrix decomposition introduced by LEE. It allows approximating any matrix V of size (n×m) and whose elements are all positive, thanks to a decomposition of the form:

$$V \approx WH \quad (5)$$

where, W and H are matrices (n×k) and (k×m). The matrix V contains the real vectors of dimension m, the matrix W contains the corresponding vectors in a space of dimension k<m and the matrix of passage H contains the basic vectors. The originality of the NMF lies in the non-negativity constraints that it imposes on W and H that is their elements must all be positive. NMF is distinguished from other matrix factorization methods by the constraint that all elements in the factorizing matrices be non-negative. Many natural signals, such as pixel intensities, amplitude spectra, occurrence counts and discrete probabilities are naturally represented by non-negative numbers thus, in the analysis of mixtures of such data, non-negativity of the individual components is a reasonable constraint. Also, non-negativity ensures that data is modeled as a purely additive combination of features, such that no cancellations can occur. This agrees with the intuitive idea of building the whole as the sum of its parts.

Algorithm: Determining the matrices W and H amounts to minimizing the distance between the matrix initial and the product W H. More precisely, we must minimize the Frobenius norm:

$$\|V-WH\|^2=\sum\nolimits_{i,j}\left(V_{ij}-(WH)_{ij}\right)^2 \quad (6)$$

Under the constraints of non-negativity. This is a non-trivial optimization problem that [LEE 1999] proposes to solve by initializing W and H randomly, then alternating the following updates:

$$H_{ij} \leftarrow H_{IJ}\frac{(W^TV)_{ij}}{(W^TWH)_{ij}}$$

$$W_{ij} \leftarrow W_{IJ}\frac{\left(VH^T\right)_{ij}}{\left(WHH^T\right)_{ij}}$$

The researchers show that the algorithm converges to a local minimum.

MATERIALS AND METHODS

ECG recording: The data is extracted from the DaISy database (Database for the Identification of Systems). The sampling frequency is 250 Hz. We used the MATLAB 2015 a on Windows 7. The mixed signal is parameterized with T = 2500 s as in Fig. 1.

The abdominal signal in Fig. 1 contains two mixed signals that of the mother MECG and that of the fetus FECG. The aim of this research is to extract the FECG signal from this single channel.

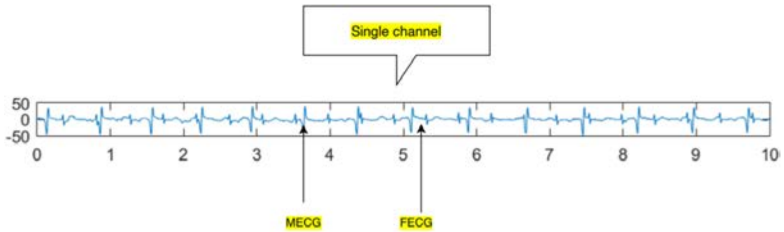

Fig. 1: Abdominal signal

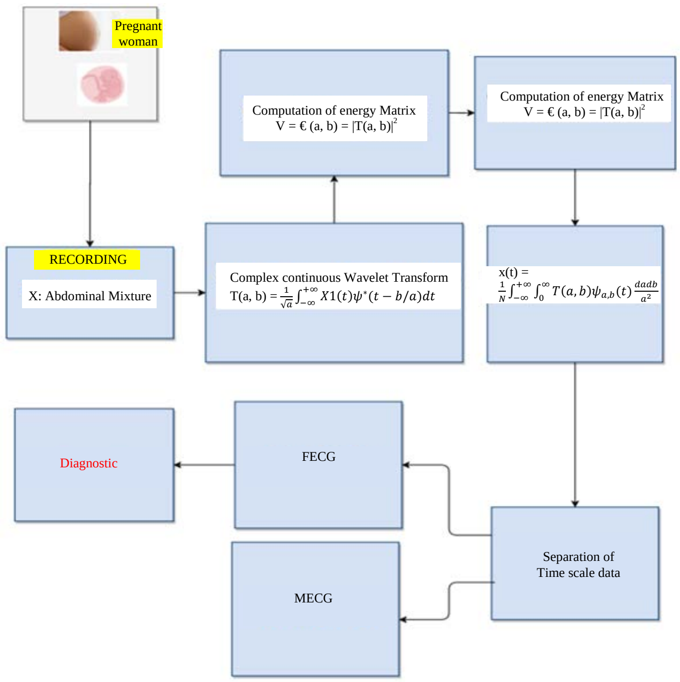

Fig. 2: Algorithm

Algorithm

Description of method of separation of time scale data: Let V the representative matrix of the time-scale image which contains all the energy information on the mixture of MECG and FECG signals. Let, V_{ij} be the element of the matrix V which we seek to extract. According to the information, we will extract from the initial matrix V we make the appropriate product of the lines of W with the columns of H (Fig. 2). Non negative bilinear model:

$$V_{ij} = \sum_{k=1}^{K} W_{i,k} H_{k,j} \quad (7)$$

Sum of products of non negative variables.

RESULTS AND DISCUSSION

Complex continuous wavelet transform and non negative factorization of V matrix: In order to construct the image times-scale by simulation we used the Haar wavelets which provided the following results (Fig. 3).

Non Negative Matrix Factorization and separation: Based on the NMF of the time-scale image, we find two matrixes:

- Image 1: Containing only the energy contribution of the fetal activity
- Image 2: Containing only the energy contribution of the of mother's cardiac activity

Then, by estimating the Inverse Continuous Wavelet Transform (ICWT) the time representation of the wave is recovered (Fig. 4, FECG). The continuity from one trace to the other enables the tracking of the waves from one image to the next. Thus, the whole profile can be treated automatically.

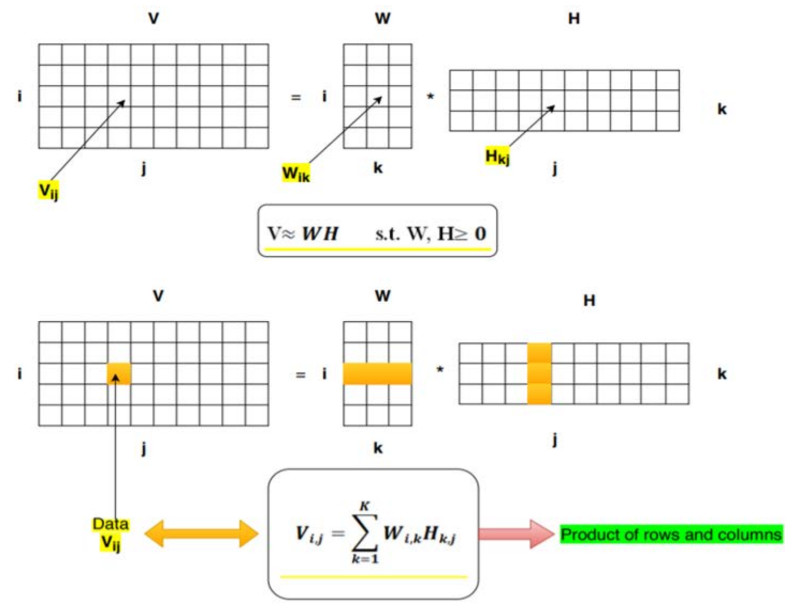

Fig. 3: Abdominal signal

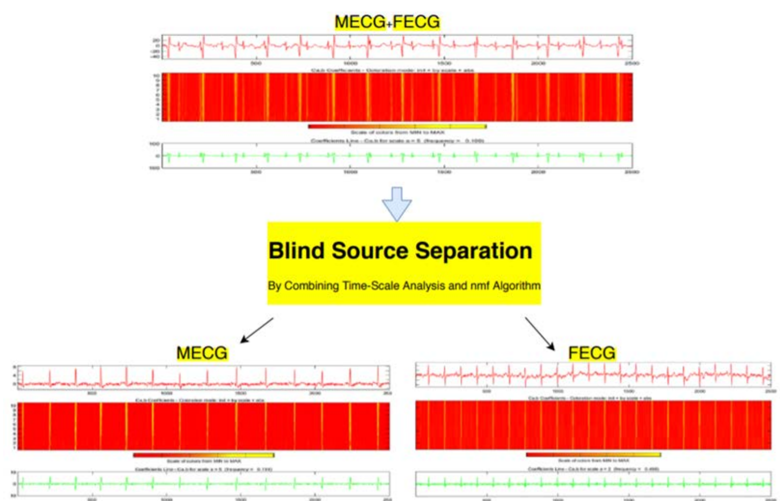

Fig. 4: Extraction of FECG signal

CONCLUSION

This study presented a new approach for the blind source separation of the FECG and MECG signals based on the continuous wavelet transform and the non-negative matrix factorization of the time-scale image. This technique can be illustrated by means of a real-life examples.

In this research, we have addressed the problem of non-invasive extraction of the fetal electrocardiogram. We have proposed a method that uses a single sensor and even allows the extraction of cardiac signals from the twins with a perfect characterization of QRS complex and this is a great addition to this area of research. Simulations were used to evaluate the performance of the method. Several perspectives can be envisaged namely the automation of the computation of the inverse wavelet transform by using databases identifying the ECG signals from the time-scale image. The present method also makes it possible to obtain the instants of the fetal peaks R and to detect abnormal beats with cardiac pathologies and at several stages of pregnancy. The new and original contribution of this work is that it makes the blind source separation from a single channel without using the classical statistical methods such as ICA, PCA[9] or decomposition methods such as SVD, EMD and NMF. And it can be developed through the use of other NMF algorithm. And this can be a major research focus for the future.

ACKNOWLEDGEMENTS

The researchers would like to thank the anonymous reviewers for their insightful comments and recommendations.

REFERENCES

01. Elshahed, M.A., 2020. Personal identity verification based ECG biometric using non-fiducial features. Int. J. Electr. Comput. Eng., 10: 3007-3013.
02. Ziani, S., A. Jbari, L. Bellarbi and Y. Farhaoui, 2018b. Blind maternal-fetal ECG separation based on the time-scale image TSI and SVD-ICA methods. Procedia Comput. Sci., 134: 322-327.
03. Ziani, S., A. Jbari and L. Belarbi, 2017. Fetal electrocardiogram characterization by using only the continuous wavelet transform CWT. Proceedings of the 2017 International Conference on Electrical and Information Technologies (ICEIT), November 15-18, 2017, IEEE, Rabat, Morocco, pp: 1-6.
04. Ziani, S., Y. El Hassouani and Y. Farhaoui, 2018c. An NMF based method for detecting RR interval. Proceedings of the International Conference on Big Data and Smart Digital Environment, November 29-30, 2018, Springer, Casablanca, Morocco, pp: 342-346.
05. Ziani, S., A. Jbari and L. Bellarbi, 2018a. QRS complex characterization based on non-negative matrix factorization NMF. Proceedings of the 2018 4th International Conference on Optimization and Applications (ICOA), April 24-27, 2018, IEEE, Mohammedia, Morocco, pp: 1-5.
06. Ziani, S. and Y.E. Hassouani, 2019. Fetal-maternal electrocardiograms mixtures characterization based on time analysis. Proceedings of the 2019 5th International Conference on Optimization and Applications (ICOA), April 25-26, 2019, IEEE, Kenitra, Morocco, pp: 1-5.
07. Deville, Y. and M. Benali, 2000. Differential source separation: Concept and application to a criterion based on differential normalized kurtosis. Proceedings of the 2000 10th European Signal Processing Conference, September 4-8, 2000, IEEE, Tampere, Finland, pp: 1-4.
08. Daubechies, I., 1992. Ten Lectures on Wavelets. 1st Edn., SIAM., Philadephia, ISBN: 0-89871-274-2, pp: 1-52.
09. Pham, D.T. and J.F. Cardoso, 2001. Blind separation of instantaneous mixtures of nonstationary sources. IEEE. Trans. Signal Process., 49: 1837-1848.