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An Efficient and Noninvasive Method to Extract Fetal Electrocardiogram from Abdominal Electrocardiogram

*Esha Ahuja[1], Faisal Shaikh[2]
[1](*Electronics, MGM's Jawaharlal Nehru Engineering College, India*)
[2](*Electronics, MGM's Jawaharlal Nehru Engineering College, India*)
Corresponding Author: Esha Ahuja

Abstract : *Monitoring health of fetus has become very important these days as many diseases are observed just after the delivery of baby. This is even causing death of baby if the disease remains undetected and hence uncured. Hence to know the well-being of fetus, the proposed method is to acquire the fetus's ECG and observing it doctors can get an idea of fetus's health. In the present paper, we describe a non-invasive method to extract Fetal ECG from mother's abdominal ECG. This method is compared with results of other methods and found efficient comparatively.*

Keywords: *Blind Source Separation (BSS), Fetal Electrocardiogram (FECG), ICA (Independent Component Analysis), Mother's Abdominal Electrocardiogram (MECG), Noninvasive.*

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I. Introduction

As per the survey in [5], one out of 125 babies is born with serious heart disease. This generates need to monitor fetal ECG and diagnose any heart defect in early stage. This can save life of baby. But extracting fetal ECG from abdominal ECG is a signal processing challenge as strength of fetal ECG is very low and abdominal ECG contains many noise signals like muscle contraction. Also, nature of mother's ECG and fetal ECG are quite similar which increases the complexity to extract good quality fetal ECG. The nature of normal ECG wave is as shown in figure 1.

The non-invasive extraction of Fetal ECG from multichannel abdominal ECG recordings is an emerging technology used for Fetal cardiac diagnosis. ICA and its extensions are the popular techniques for the extraction of FECG, which are proved to be more robust and accurate than most conventional methods [6]. This algorithm works as a filter for extracting the FECG from multichannel maternal recordings. Noise reduction and subsequent extraction has been attempted by various Independent Component Analysis (ICA) algorithms. ICA comes under the classification of BSS techniques that can be applied to biomedical signal processing by making an additional assumption of independence of original signals. Some of the previous approaches to ICA are FastICA, INFOMAX, Joint Approximate Diagonalization of Eigen Matrices (JADE), MeRMaid etc.

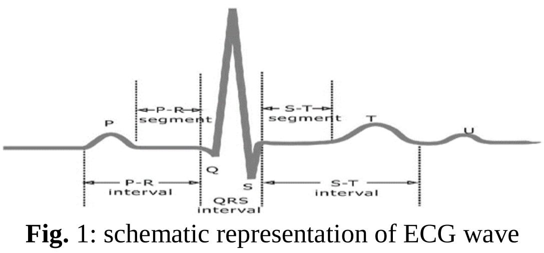

Fig. 1: schematic representation of ECG wave

II. Method

ICA is a method to obtain matrices [X] and [A] such that column vectors of the matrix $[X]^T$ are independent to each other that means the Kurtosis values computed for the column vectors are maximum. Kurtosis is the statistical parameter used to measure the Gaussian nature of the signal.

Kurtosis is inversely proportional to the Gaussianity of the signal. Note that the kurtosis values are maximum for independent signals compared to the mixed signals that means Independent signals are more nongaussian compared with mixed signals. Mathematically kurtosis is computed using the formula as displayed below, where E[X] is the expectation of the vector X.

Kurtosis = E [X^2]-3{E [X^2]}^2

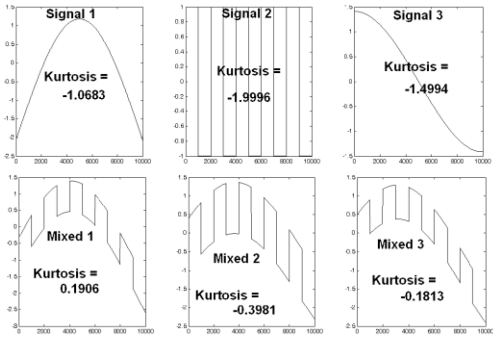

fig. 2: three independent signals and the corresponding mixed signals along with the kurtosis values

III. Equations

The basis of most ICA approaches is a generative model, that is, a model that describes a method to how the measured signals are generated. The model takes an assumption that the measured signals are the product of instantaneous linear combinations of the independent sources. Such a model can be mathematically represented as:

$$x_i(t) = a_{i1} s_1(t) + a_{i2} s_2(t) + \cdots + a_{iN} s_{1N}(t) \qquad (1)$$

For i = 1, 2…. N.
s = source signal.
x = mixed signal.
a = constant.

Note that this is a series of equations for the N different signal variables, $x_i(t)$. While considering the ICA model equation, we can ignore the time function. Indeed, most ICA approaches do not take the consideration of ordering of variable elements; hence, the fact that s and x are time function is irrelevant.

In matrix form, above equation can be represented as follows:

$$\begin{bmatrix} x_1 \\ \vdots \\ x_n \end{bmatrix} = A \begin{bmatrix} s_1 \\ \vdots \\ s_n \end{bmatrix}$$

From the algorithm section, the other elements of matrix B are computed using the following iteration equations:

$$b_{11}(t+1) = E[(b_{11}(t) z_{1i} + b_{21}(t) z_{2i})^3 z_{1i}] - 3 * b_{11}(t)$$
$$b_{21}(t+1) = E[(b_{11}(t) z_{1i} + b_{21}(t) z_{2i})^3 z_{2i}] - 3 * b_{21}(t)$$
$$b_{12}(t+1) = E[(b_{12}(t) z_{1i} + b_{22}(t) z_{2i})^3 z_{1i}] - 3 * b_{21}(t)$$
$$b_{22}(t+1) = E[(b_{12}(t) z_{1i} + b_{22}(t) z_{2i})^3 z_{2i}] - 3 * b_{22}(t)$$

The columns of the matrix B are made orthonormal to each other. This can be explicitly performed in every iteration, after updating the values using the equation [1].

IV. Algorithm

The mixed signal y(t) refers to the abdominal signal which is a mixture of Fetal ECG, maternal ECG, muscle contraction noise, baseline wandering error, electrode leads noise etc. The mean variance of these signal is removed and the signal y(t) is converted to z(t). For this purpose, Hotellilng transformation can be used. Matrix B is actually the inverse of matrix A which is first initialized. Different noises are removed using particular filters during the pre-processing step. Later the ICA Algorithm is applied on the data to finally acquire the Fetal ECG. The results of this algorithm are discussed in the preceding paragraph under Experiments and Results.

Steps of the used algorithm are as follows:

1. Given mixed signals y_1(t) and y_2(t) are converted into z_1(t) and z_2(t) such that the covariance matrix computed using the converted signals z_1(t) and z_2(t) is the identity matrix
2. Initialize the values for the matrix B such that $B^T B$=[I]
3. Update the elements of the matrix B using:
   $b_{11}(t+1) = E[(b_{11}(t) z_{1i} + b_{21}(t) z_{2i})^3 z_{1i}] - 3 * b_{11}(t)$
   $b_{11}(t)$ is the value for b_{11} in t^{th} iteration
   $b_{11}(t+1)$ is the value for b_{11} in $(t+1)^{th}$ iteration.
   Similarly, other elements of matrix B are computed.
4. Columns of the matrix B is made orthonormal to each other.

5. Repeat step 3 and step 4 for 'N' Iteration.

Independent signals are obtained by multiplying B^T with the Z matrix

V. Results

Abdominal signals used for this method are taken from the database of [7]. Applying the algorithm described in the section above, following results are obtained. Figure 3 represents the measured abdominal signal. Figure 4 represents the estimated FECG signal after applying the kurtosis function. Figure 5 represents the intermediate signals after preprocessing the measured signal. Figure 6 represents the extracted FECG signal.

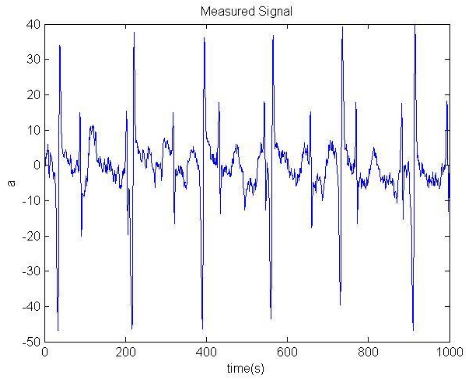

Fig. 3: measured abdominal signal from database

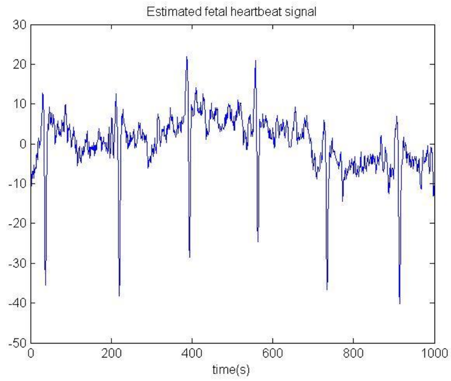

Fig. 4: estimated FECG signal

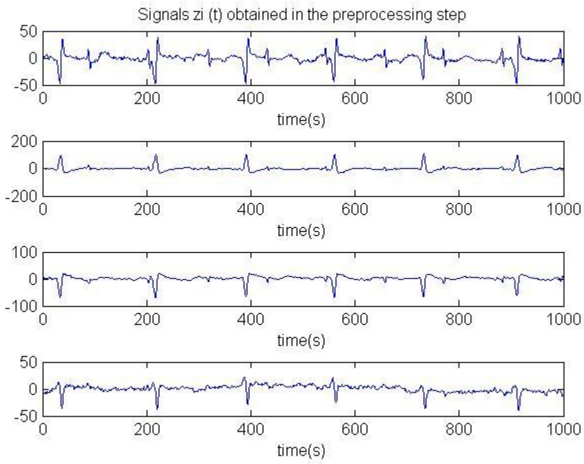

Fig. 5: preprocessing signals

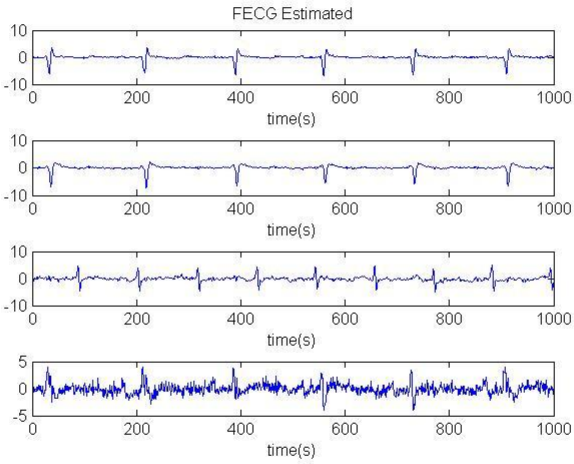

Fig. 6: fetal ECG signal extracted using algorithm

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