Extraction of Fetal QRS Complex from Abdominal ECG Signals

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Abstract: Background: Extraction of Fetal ECG signal from non-invasive abdominal ECG signal is an important clinical application. Fetal ECG signal provides significant and valuable information about the fetal heart growth and health condition. Objective: Abdominal signals are usually corrupted by high amplitude maternal ECG signals and often found superimposed with the Fetal ECG signal. Suppression of maternal peaks for proper Fetal ECG signal extraction is attempted in our work. Method: A multichannel Fetal ECG signal extraction procedure is proposed in this work using Multivariate Empirical Mode Decomposition (MEMD) and Singular Value Decomposition (SVD). Observation: Patient dataset from three pregnant women is used for evaluating our procedure. The proposed method produced an average detection accuracy of fetal heart rate of 85.33% (min: 75 and max: 100).

Keywords — Abdominal ECG, Multivariate Empirical Mode Decomposition, Singular Value Decomposition, Fetal ECG

I. INTRODUCTION

Fetal ECG monitoring plays a vital role in the health condition of the fetal. It helps to increase the effectiveness of proper treatment and prevent cardiac defects if diagnosed at an early stage during pregnancy (1). Cardiac defects are the most common birth defects that may cause sudden prenatal death (2). Cardiac abnormalities occur due to various reasons like inherited disorder, genetic syndrome and environmental factors like infections and misuse of drugs during pregnancy. Congenital heart defects develop during the heart formation and can affect any part or functions of the heart (3). FECG contains crucial information about cardiac functions of the heart. There are diverse characteristics of FECG such as fetal heart rate (FHR), QRS waveform, and dynamic behavior that can be used for diagnosis. They are vital in determining the fetal life, fetal development, fetal maturity, and most importantly the existence of congenital heart disease (1).

Invasive fetal electrocardiography has proven to be an effective tool for specific structural cardiac defects only during labor and not during pregnancy (1). Moreover, fetal electrocardiography has been restricted to coronary heart disease due to specific fetal positioning that chokes the umbilical cord, and the fetal monitoring is based entirely on fetal heart rate (FHR). It does not incorporate the fetal ECG waveform characteristics that are essential for fetal cardiac evaluation during pregnancy (4). Furthermore, the non-invasive fetal electrocardiogram (FECD) techniques are not widely analyzed, as fetal brain activity, maternal ECG, EMG, and other movement artifacts easily contaminate it (5). Moreover, the baseline drift, power-line interference, gestational age, position of the electrodes, skin impedance and random electrical noise caused by human movement, baseline drift due to poor contact of measurement electrode are some external noises that can affect the fetal ECG separation.

Maternal electrocardiogram (MECG) is a dominant noise mixed with FECG in maternal electrocardiogram (AECG) signal. Since the amplitude, strength and magnitude of MEGC is greater than that of the FECG it is often superimposed with MECG and other noises (1). As the FECG signals are non-stationary and non-linear in nature, the noise suppression has to be done without losing main information from FECG signals. For this purpose, an efficient noise filtering technique is required. Current literature suggests many signal-processing techniques to suppress the noises in the Fetal ECG signal (1). The majority of these algorithms are based on blind source processing and linear filtering. It includes methods such as Periodic Component analysis (6), Independent component analysis (ICA) (7) and adaptive linear filtering (7–9,15,16). In our work, an attempt to use multichannel abdominal signals in the empirical mode domain (EMD) for fetal ECG separation.

II. MATERIALS AND METHODS

The maternal signal is the key noise component in AbECG and it superimposes with the fetal signal.
In this work, recently developed Multivariate Empirical mode decomposition technique is used to separate the fetal signal from maternal components. The proposed method suggests the usage of multivariate signal processing technique, as it can process multichannel recording directly in comparison to other conventional methods that can process and analyze only one single channel at a time (8).

**Figure 1 Block diagram of the proposed Fetal ECG extraction procedure**

Figure 1 show the various steps involved in the separation of fetal ECG signals from abdominal signals. In this work, four abdominal ECG signals acquired from three pregnant women are used in the evaluation of the proposed technique. Initially, MEMD is applied on the input signal and it is separated into multivariate intrinsic mode functions (IMF). The IMFs are further analyzed and IMFs related to fetal activity are identified based on the time evolution. The selected fetal related IMFs are combined for further processing. Here, we apply singular value decomposition to separate the signal into its various subspaces. The prominent singular subspace is used to reconstruct the fetal ECG signal, and the multichannel signal is then averaged into a single composite signal.

**A. Clinical Data Set**

The abdominal ECG recordings were taken from PHYSIONET.ORG for duration of 10s and were randomly selected for the analysis (10). The readings are recorded by placing electrodes at various positions of the abdominal regions of the pregnant women. They contain four abdominal channels. The database also contains direct Fetal ECG signal recorded from the fetal scalp region. The Fetal QRS complex is annotated for comparative study of fetal extraction algorithms. We test our proposed methodology with the direct fetal ECG signal for validation. In Figure 2, the abdominal ECG signals taken from four channels are shown. In addition, the figure 2 also shows the direct Fetal ECG signal.

**Figure 2 Original abdominal ECG recording of a test subject**

**B. Empirical Mode Decomposition (EMD)**

EMD technique relies on fully data-driven mechanism. It is a method to decompose non-linear and non-stationary time series. It can decompose a signal without leaving the time domain and does not require any prior assumptions about the composition of the signal. EMD decomposes the signal into monotonic components called Intrinsic Mode Functions (IMF) of different time scales (11). IMFs could change over time, so the EMD have no prior assumption about the stationary part of the signal. EMD deals with analyzing single channel natural signals and it is best suited for non-linear and non-stationary signals.

However, EMD technique also has certain shortcomings (12):
- The numbers of channels in each individual IMF are different.
- The relationship between the IMF channels were investigated and there is no inter-channel dependency in standard EMD implementation .
- The algorithm decomposes only single IMF channel at a time.
- EMD algorithm needs to be modified to handle the mode-mixing problem.

Therefore, in order to allow multivariate processing of the ECG signals, a recent improvement in EMD technique used for processing multivariate signals called Multivariate Empirical Mode Decomposition (MEMD) was proposed by Rehman and Mandic(12). The successful implementation of
MEMD in various signal-processing applications motivated us to use MEMD in this work (13).

C. Multivariate Empirical Mode Decomposition (MEMD)

MEMD technique is a multivariate or n-variate extension of EMD. This technique converts the multi variate signal into multi-dimensional envelopes. In standard EMD, the local mean is calculated by taking the average of upper and lower envelopes, which in turn is obtained by interpolating between the local maxima and minima. However, in multivariate EMD, the local maxima and minima are defined from multipoint signal projections (12).

MEMD process the multichannel signal by generating n-dimensional envelopes from signal projections along different directions in n-dimensional spaces. The local mean is calculated by taking their average (12).

D. Proposed Fetal ECG extraction procedure

The multivariate signal processing technique based on MEMD is used for extracting the fetal components from the abdominal signals by decomposing the signal into multivariate IMFs. The proposed methodology enables the selection of IMFs with fetal components and the elimination of IMFs with maternal and noise components.

The following section describes the steps involved in our fetal ECG extraction procedure:

1: Consider a multichannel (n=4) abdominal signal \( f(t) \). We select duration of 10s to decompose the input signal into IMF signals. This reduces the computational complexity of MEMD.
2: Perform multivariate empirical mode decomposition of the input signal such that
\[
\dot{f}(t) = C(t) w_{p:t}
\]
The step yields a p-variate intrinsic mode function (IMF). It is defined by \( C(t) \).
3: Select the appropriate IMF components \( C_2(t) \) and \( C_3(t) \) that correspond to fetal activity. It is done by visually analyzing the IMF signals. Here we select IMF-2 and IMF-3. IMF-1 is ignored as it corresponds to high frequency noise components.
4: Combine the selected IMFs into an empirical mode signal. Here, we apply SVD to separate the IMF signal into various signal subspaces. We select a prominent signal subspace that corresponds to first singular value.

\[
[u, s, v] = \text{svd}([IMF_{23}(t)])
\]

\[
FECG(t) = u(:,1) * s(1,1) * v(:,1)'
\]

Here FECG is the averaged signal obtained by reconstructing the signal subspace from the prominent singular value.

III. RESULTS AND DISCUSSION

In order to validate the proposed procedure, clinically verified data set taken from PHYSIONET abdominal ECG database (adfecgdb) is used in our work. The database consists of four abdominal recordings taken from five test subjects. We have used three test dataset for evaluating the proposed fetal ECG extraction procedure. Figure 2 shows the abdominal recording of one test subject. The four abdominal signals show both fetal wave (QRS complex marked by low amplitude) and the maternal wave (QRS complex marked by high amplitude). Moreover, the visual analysis of the AbECG signals shows that there is no separation between the fetal and maternal ECG waveforms. Our proposed method uses a multistage maternal suppression procedure. First, we compute the IMF signals of the multichannel AbECG signals. We select IMF-2 and IMF-3 of the decomposed signal for further processing. Figure 3 shows the combined IMF signal by integrating IMF-2 and IMF-3.

Second, we use the SVD to separate the filtered signal into various signal subspaces. Here, we consider only the prominent signal subspace constructed from the first singular value. Thus, further suppressing the maternal noises in the filtered ECG signal. Figure 4 shows the reconstructed Fetal ECG signal obtained from the first singular subspace.
Figure 4 Reconstructed Fetal ECG signal by using the first singular subspace

The filtered Fetal ECG signal is visually scored with the direct Fetal ECG recording provided with the database. We compute the detection accuracy of fetal QRS complex using our proposed method as shown below (14).

\[
\text{Accuracy} = \frac{\text{No. of Est. FHR}}{\text{No. of Act. FHR} + \text{No. of Maternal} + \text{No. of Missed FHR}}
\]

(4)

We calculate the number of R-peaks in the fetal and maternal components present in the signal. The performance evaluation is based on the following factors:

- Number of Fetal R-wave detected (Est. FHR)
- Number of Maternal peaks (Maternal).
- Number of missed Fetal R wave (Missed FHR)
- Detection accuracy (%)

Here Act. FHR signifies the actual FHR obtained by visual scoring of the direct fetal ECG signal. It is used for determining the detection accuracy of the proposed method. Table 1 shows the performance measures of the multichannel Fetal ECG extraction algorithm proposed in this work. The detection accuracy of three test subjects is shown in the table 1.

Table 1 Performance analysis of the proposed Fetal ECG extraction method

<table>
<thead>
<tr>
<th>S.No</th>
<th>Actual FHR</th>
<th>Estimated FHR</th>
<th>Maternal FHR</th>
<th>Missed FHR</th>
<th>Detection Accuracy (%)</th>
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<tr>
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IV. CONCLUSION

Multivariate signal processing of AbECG signal is attempted in this paper. The AbECG signals from four channels are decomposed into \( p \)-variate IMFs. Multistage maternal ECG suppression is tried in this work. An average fetal heart rate detection accuracy of 85.33% is obtained using our method. Our work successfully implements MEMD method in multichannel Fetal ECG extraction procedure. A post processing of the filtered ECG signal needs to be investigated for further improvement in the detection accuracy.

Acknowledgments

None

Conflicts of Interest

None

REFERENCES


