

Fetal Electrocardiogram Extraction From Abdominal Electrocardiogram Using Wavelet

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ABSTRACT

Fetal electrocardiogram (FECG) is a signal from an abdominal electrocardiogram (AECG), obtained using non-invasively. FECG is very important to find the situation of fetal health. This article presents a method for FECG extraction from the AECG signal employing Wavelet. Wavelet is used to remove the noise of muscle and fetal movements in the mother's abdomen. Parts of the wavelet result are eliminated such that the signal only consists of QRS fetal. The method is examined using the dataset of the abdominal database from the Physionet. The performance found using this method is 95.01% in terms of accuracy.

Keywords: *Fetal, Electrocardiogram, Abdominal, Wavelet.*

1. INTRODUCTION

The heart of the fetus is one of the organs that has experienced growth during pregnancy [1]. Fetal heart rate (FHR) and fetal electrocardiogram (FECG) morphological analysis are important things to do and are used in fetal health checks [2]. Heart defects are the main and most common cause of fetal death at birth because every year, one in 125 babies born has multiple congenital heart defects [3].

An electrocardiogram (ECG) signal is the result of a record of electrical activity in the heart in humans. The results of the heart's electrical activity record can also be performed on pregnant women known as Abdominal ECG (AECG). AECG is a combination of maternal ECG (MECG) signals, fetal ECG (FECG), fetal activity, and noise [4]. FECG can be performed in a waveform analysis process to obtain important information about the physiological state of the fetus [5]. FECG has characteristics in heart rate, waveforms, and dynamic behavior that can determine fetal life, fetal development, fetal maternity, and congenital heart disease [6].

Fetal and maternal heart signals need to be analyzed to overcome problems and dangers during pregnancy [7]. There are several methods that can be used to perform fetal heart examinations, namely the invasive method and the non-invasive method [8]. The invasive method is performed directly when the fetus is still in the mother's womb called the Transvaginal Fetal Scalp Electrode (FSE). This method can provide very accurate results when measuring fetal

heart signals [9]. This method is still rarely done since it is risky to be conducted.

The non-invasive method is done indirectly by attaching electrodes to the mother's abdomen to obtain fetal heart signals. This method is one of the safest methods for knowing fetal heart signals through the mother's heart. However, this method has several drawbacks, including the influence of the signal recorded by the mother's muscle activity, breathing, maternal digestion, sounds coming from the electrodes, and the mother's skin [9].

To obtain the FECG requires a method to process the signal source so that fetal and maternal signals can be separated. Signals recorded on several recording devices often interrupt these signals in the form of noise and artifacts [10]. MECG signal is a signal that can affect FECG signals because of the frequency spectrums of each signal source overlap. The filtering process to reduce the noise level is less effective to do. Therefore, another technique is required to obtain a better FECG signal acquisition that is being done in this study. [6].

The method that was used in this study was Wavelet transform analysis, which was able to separate fetal signals from the maternal signals. The next section explains the methods that have been used by showing the results, discussion, and conclusions.

2. MATERIALS AND METHODS

The data used as the material for this study were accessed from the Physionet, namely the Abdominal and Direct Fetal

Electrocardiogram Database (adfecgdb). The data of AECG consisted of 5 patients, namely patients r01, r04, r07, r08, and r10, with each patient having four abdominal signals. Method of Wavelet Transform. This study applied the method of wavelet transform (WT) to extract the FECG signal from the AECG signal. WT is a method that has the ability to do the multi-resolution analysis of a signal so that it can present information in the form of time and frequency well.

Fig. 1, explain the extraction process from the AECG signal as described in the following stages:
 Step 1. *AECG signal*: The data used was obtained from 5 patients, each of which had four abdominal signal data records from the mother's abdomen with four different electrodes. Step 2. *Baseline wander removal*: The signal was corrected using a baseline wander that was used to eliminate unwanted noise. Step 3. *High pass filter*: The filtering process is carried out using a high pass filter that works to eliminate unwanted low-frequency signals. Step 4. *Wavelet transforms*: Wavelet transform used in this study was Continuous Wavelet Transform (CWT), which functions to perform multilevel data

decomposition. Step 5. *Thresholding to find maternal R peak*: The threshold process was carried out to find the initial limit of the peak of the R of mother and the final limit of the peak of the R of the mother. The threshold value used on the R of the mother was $0.3 \times \max(\text{CWT})$. Step 6. *Removing maternal R peak*: After obtaining the peak of R from the mother the removal process, which was the part of the peak of the mother, was carried out. Step 7. *Thresholding to find fetal R peak*: The decomposition process using CWT was carried out in search of the fetal R peaks. The threshold process was carried out to find the initial and final limits of the peak R fetal. The threshold value used in the fetal R was $0.1 \times \max(\text{CWT})$. After these steps were performed, a FECG signal from each of the four abdominal patients could be obtained. Through the test results that have been obtained, it can then be determined the performance of the system that has been used. The determination of performance is done by using two parameters, namely sensitivity and accuracy [11,12].

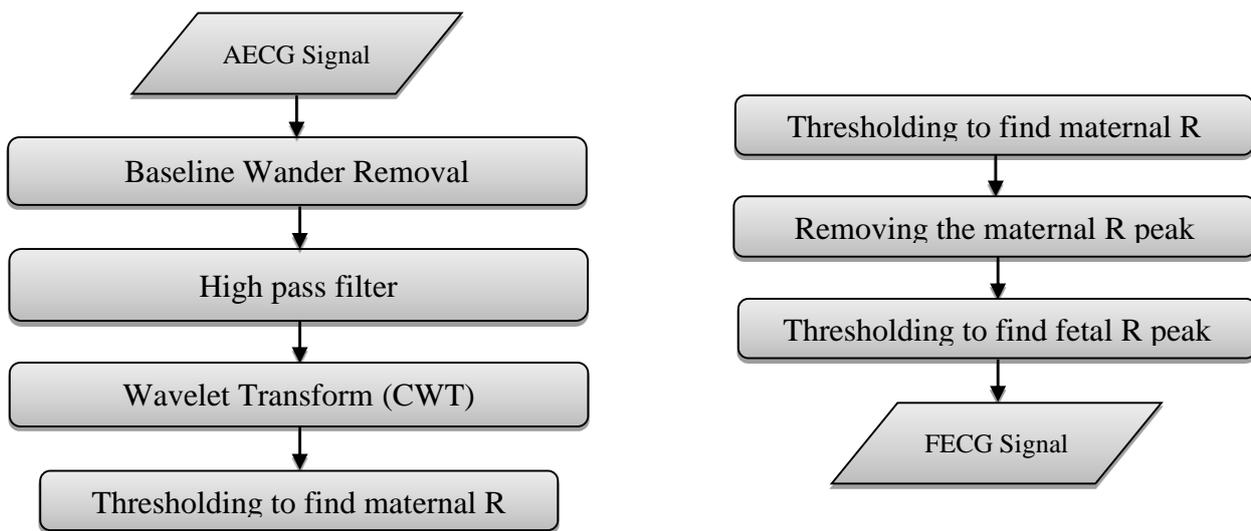


Figure 1. Extraction to find FECG signal from AECG

$$Accuracy (\%) = \frac{TP+TN}{TP+TN+FP+FN} \times 100 \tag{1}$$

$$Sensitivity(\%) = \frac{TP}{TP+FN} \times 100 \tag{2}$$

Where: TP (True Positive) : the number of fetal ECG detected correctly
 FP (False Positive) : the number of fetal ECG detected incorrectly
 TN (True Negative) : the number of maternal ECG detected incorrectly

3. RESULTS AND DISCUSSION

Research on the extraction of FECG from AECG by using a wavelet transform has been carried out. The data used was obtained from 5 pregnant female patients with 38-41 weeks gestation, each of which had four abdominal signals. The process that has been done can be explained in the figures taken from the results of the data processing.

Fig. 2 (a), is a data recording of fetal signals obtained through the invasive methods and Fig. 2 (b), mixed of the fetal and maternal signal data, which was obtained using a non-invasive method which takes the recording of data signals through the mother's abdomen and is known as AECG. The AECG signal data that has been obtained was carried out by the baseline wander removal process, whose final results can be seen in Fig. 2 (c) and Fig. 2 (d).

The filter process was then performed using a high pass filter the results of which can be seen in Fig. 3 (a), after the filter process was continued with the processing using Wavelet transform that was CWT and the results of the process can be seen in Fig. 3 (b). This CWT process was carried out at first on the maternal signal to obtain a clearer form of the maternal signal.

Fig. 4, is a combination of the results of the filter and the CWT process, and from this figure, the three colors of red, green, and blue can be seen. These colors show the differences during the process that has been done. Blue indicates the results of the filter process, and green indicates the results of the CWT process, and red indicates the results of the filter from the CWT process to obtain a clearer maternal signal.

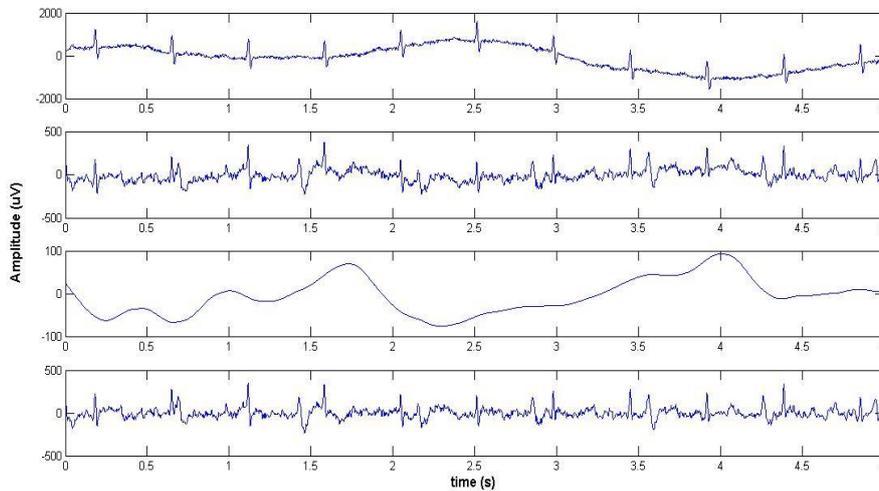


Figure 2. The signal AECG using baseline wander processing

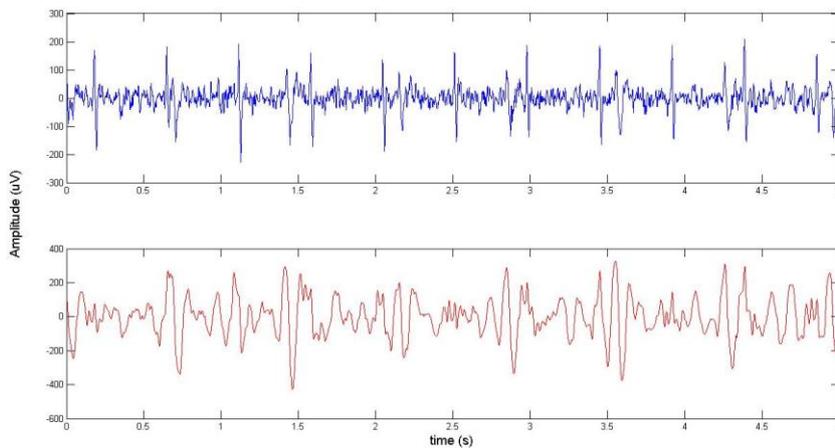


Figure 3. (a) Filter of AECG signal and (b) CWT of AECG signal

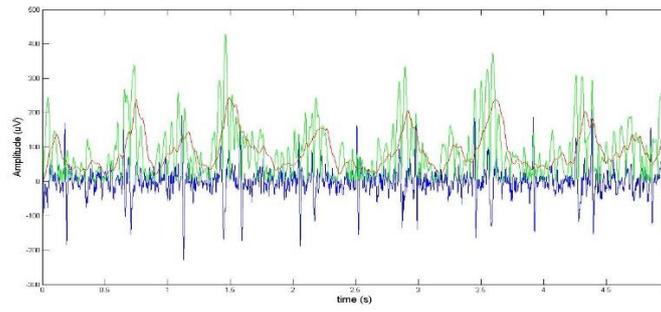
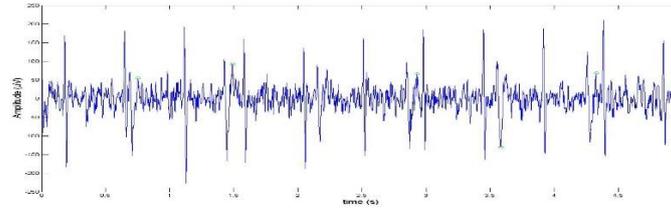


Figure 4. CWT processing to find maternal R peak

a.)



b.)

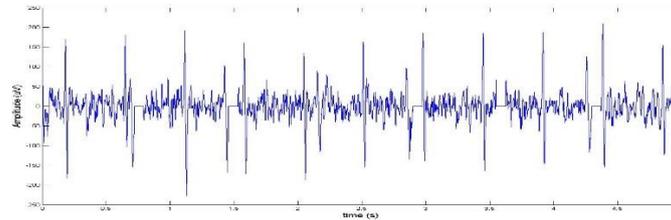


Figure 5. (a) Thresholding to find maternal R peak and (b) Removing maternal R peak

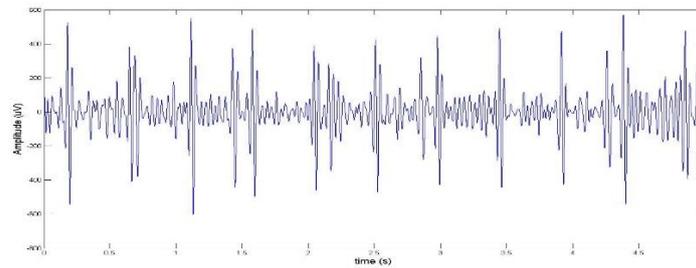


Figure 6. CWT process to find fetal R peak

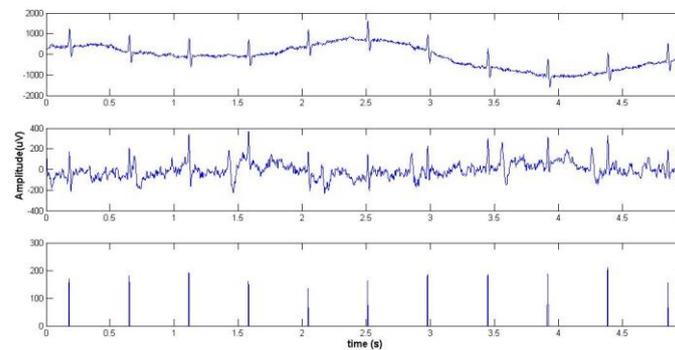


Figure 7. (a) Fetal electrocardiogram signal using the invasive method, (b) abdominal

The next process was the threshold to detect the initial limit of the maternal R peak and the limit of the maternal R peak that can be seen in Fig. 5 (a). After the threshold process on the maternal signal was carried out, the process was removed, which aims to eliminate the maternal signal that can be seen in Fig. 5 (b).

Furthermore, the CWT process was repeated to determine the R peak signal in the fetal. The results of the fetal CWT process can be seen in Fig. 6.

The electrocardiograms signal extraction results that have been obtained using the wavelet transform method, CWT, can be seen in Fig. 7. Based on this, Fig. 7 (a) displays the FECG signal obtained through the invasive method used as a comparison of the results of the FECG signal using the non-invasive method. An abdominal electrocardiogram signal is a result of recording the signal that was still combined between the maternal and fetal electrocardiogram signals, as shown in Fig. 7. (b).

From the abdominal electrocardiogram signal obtained, then the separation process was carried out to obtain the fetal signal using the wavelet transform method, CWT. Fig. 7 (c), shows the results of fetal electrocardiogram signals that have been extracted using the wavelet transform method.

From the electrocardiogram signal that has been obtained, then the process of measuring work performance in the form of accuracy and sensitivity values was carried out. The comparison of the results of the accuracy value that has been done to obtain the results of FHR extraction with different methods in the research that has been done can be seen in Table 1.

Table 1. Result of Accuracy and sensitivity performance on fetal electrocardiogram

Data	Lead	Acc (%)	Se (%)
r01	Abd1	90.22	96.85
	Abd2	86.75	97.04
	Abd3	84.23	95.09
	Abd4	91.17	91.24
r04	Abd1	47.43	65.71
	Abd2	85.69	90.26
	Abd3	85.21	87.82
	Abd4	86.17	87.48
r07	Abd1	57.21	85.59
	Abd2	82.98	96.26
	Abd3	89.79	98.62
	Abd4	91.57	97.91
r08	Abd1	82.37	95.05
	Abd2	95.01	99.18
	Abd3	90.01	98.10
	Abd4	84.55	89.81
r10	Abd1	83.41	93.79
	Abd2	84.39	93.71
	Abd3	58.78	84.89
	Abd4	81.22	91.91

Almost all patients on each abdomen showed good results, but in some patients also showed poor results, with r04 data on abdomen 1, 47.43% accuracy value and 65.71% sensitivity, r07 data on abdomen 1, accuracy value 57.21% and sensitivity 85.59% and r10 data on abdomen 3 with accuracy values of 58.78% and sensitivity of 84.89%. This can be influenced by

activities such as the baby's movements on the mother's abdomen, the work of the intestine, and others when data is taken. Work performance for the best accuracy value obtained in r08 abdomen 2 data is 95.01%, and the lowest work performance in r04 abdomen 1 data is 47.43%.

Table 2. The results of the comparison of several FHR extraction methods that have been carried out

Author	Description	Dataset	Acc (%)
Yuan et al. [13]	Fast ICA	Four-channel AECG signal	98.78
Lo et al. [1]	Deep Learning	Four signals from the maternal abdomen and one reference signals from fetal head	92.65
Wilson et al. [14]	Fast ICA	151 channel array from the patient	99.6
Gupta et al. [15]	MEMD techniques	Four mother's abdomen	98.3
Yuan et al. [13]	Fast ICA	Four-channel AECG signal	98.78

4. CONCLUSION

Research on fetal electrocardiogram signal extraction has been carried out using wavelet transform method. This method separates maternal and fetal electrocardiogram signals. From the research that has been done, it was obtained an accuracy of 95.01% in the r08 abdomen 2 data. However, accuracy in the patients and abdomen that has been done also shows a smaller accuracy. Thus, the filter and wavelet transform process have shown an important role in fetal ECG extraction.

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