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Wavelet Analysis on FECG Detection using Two Electrodes System Device

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Abstract: Fetal electrocardiogram (FECG) signal detection during pregnancies is very useful in assessing fetal condition. Doppler ultrasound is very common in non-invasive FECG detection. It is safe, but inaccurate, highly sensitive to noise and the success of the measurement depends on the positioning of the probe. Recently, there are many research use non-invasive Ag/AgCl in FECG detection. However it involves large number of electrode during measurement. In addition, complex structures of signal processing are required. A study has been made on FECG detection using two electrodes biopotential device without reference electrode. Best possible electrode placement for maximum FECG waveforms detection has been identified. The FECG signals are successfully detected at 0.028Hz after processed using wavelet analysis.

Keywords: FECG, wavelet transform

1.0 INTRODUCTION

Fetal monitor is really useful in assessing high risk pregnancies such as diabetes, high blood pressure and problem with fetal growth. Through monitoring, it can de distinguish either the baby is in good condition or shows a distress or hypoxia response. From Fetal electrocardiograph (FECG), fetal heart rate, amplitudes of different waves and duration of the waves, segments and intervals can be obtained. Unfortunately, it only can be done if FECG is monitored invasively. Due to the low SNR in non-invasive method, only R-peaks can be detected and P and T waves remain hidden [1]. FECG detection in this research is a very challenging task due to the no standard position for FECG detection. Furthermore, FECG detection using two electrodes system device with no reference electrode make it harder.

Currently, a lot of methods for FECG have been done for FECG extraction. This include least square acceleration (LSA) and adaptive impulse correlation (AIC) [2], linear prediction (LP) and segmentation linear prediction (SLP) [3], correlation and non-correlation function [4], and blind source separation (BSS) [5]. Some of the methods are successful techniques for FECG extraction. However, most of the method requires multi-channel signals and thus causing structural complexity.

Two electrodes system device without reference electrode is used for FECG detection in this research. Since, there is no standard position of electrodes for FECG detection; therefore comparison between two placements of electrodes has been made to find the best measurement of FECG. The signals then are processed using wavelet analysis. Discrete Wavelet Transform (DWT) was used for de-noise unwanted signal and Continuous Wavelet Transform (CWT) for signal detection.

2.0 FECG DETECTION USING TWO ELECTRODES SYSTEM DEVICE

Two electrodes system device without reference electrode is used for FECG detection. The electrodes were placed to the bottom of the maternal abdomen. It is chosen after a comparison was made between electrode placement at the top (position I) and at the bottom (position II) of maternal abdomen. In addition, according to the [6], the amplitude of the maternal ECG will be reduced by 90% when the electrode is placed at the lower abdomen.

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The comparisons between both positions are shown in Figure 1 and Figure 2. The measurement of abdominal signal and maternal ECG signal were recorded at the same time as it easier to make any comparison between the signals. Position I was placed with two Ag/AgCl sensing electrodes at the top of the abdomen, about 3cm from center of the abdomen.

Black arrow in the both figures indicate the MECG signal, red arrow is for FECG and green arrow for unwanted signal or known as noise. Black dashed lines indicate that maternal ECG correlates to the signal that is detected in abdominal record. As in Figure I, we conclude that MECG signals can be detected in abdominal signal at Position I. This is because, the position of the electrodes are close to maternal heart, rather than position II. According to the Figure 1, it shows that the MECG signal in abdominal recording are very low voltage amplitude compared to other detected signals. However, the R-peak for MECG still can be identified.

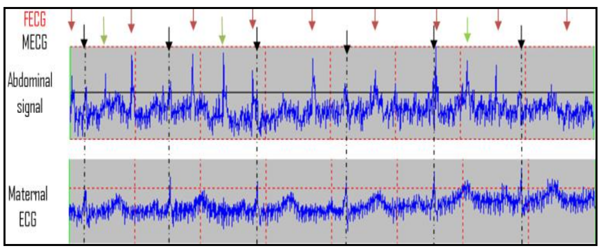

Fig. 1 Comparison between maternal ECG and AECG signals for Position I

For position II, two Ag/AgCl electrodes have been attached to the bottom of the maternal abdomen. The results in Figure 2 show that, maternal ECG is very low and hard to detect in the abdominal measurement. According to the results, the positions of these electrodes give less interference from mother ECG signal. Due the very low amplitude, the maternal ECG can be ignored.

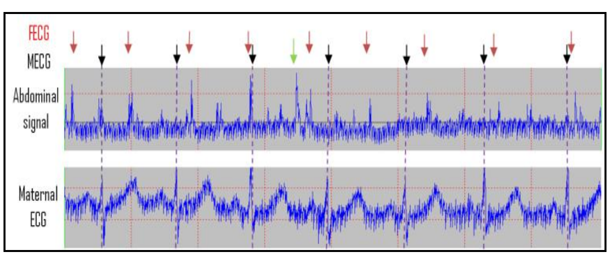

Fig. 2 Comparison between maternal ECG and AECG signals for Position

Figure 3 show Fast Fourier Transform (FFT) results for MECG, abdominal signal for position I and II. It show that strong signals exist in MECG is also exist in abdominal signals in position I compared to position II. FFT of both positions strengthen that FECG is easier to detect in position II of electrode.

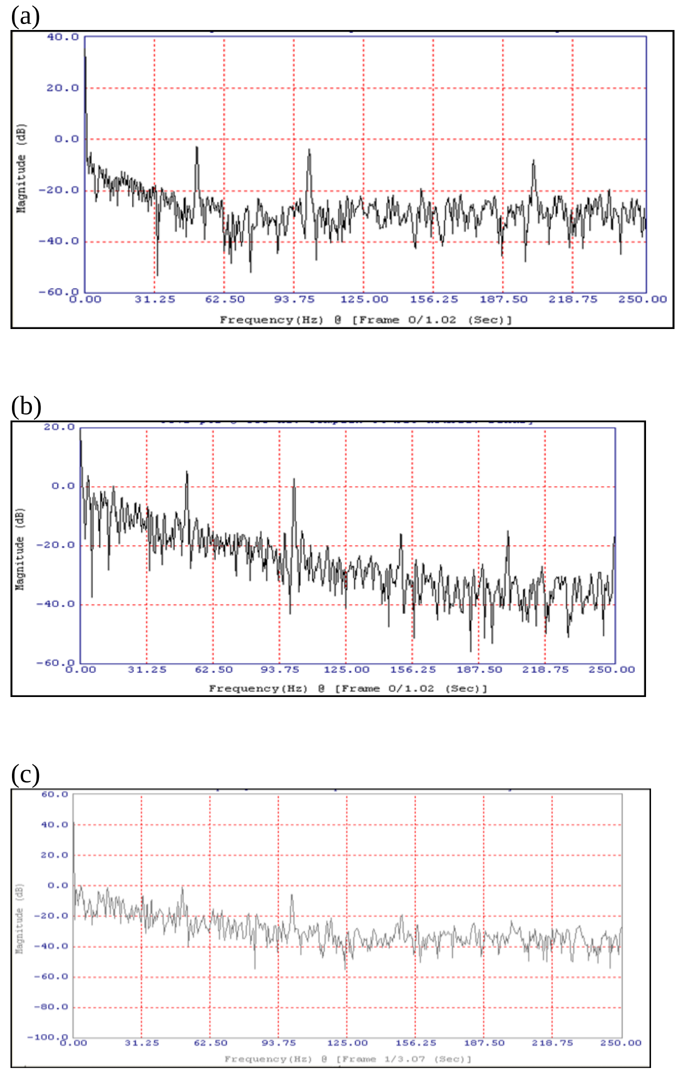

Fig. 3 (a) FFT of MECG, (b) Abdominal signal in position I, and (c) Abdominal signal in position II

3.0 FECG DETECTION USING WAVELET ANALYSIS

Wavelet analysis is very useful to de-noise and also used for detection. By using the Matlab program which contains very good wavelet toolbox, One Dimensional Wavelet 1-D and Continuous Wavelet 1-D are used. Through Wavelet 1-D, non-stationary signal like FECG can be de-noised, while Continuous Wavelet 1-D used for signal detection. De-noising through wavelet transform is

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described in three sections. First, decompose the signal to few frequency bands, second; modifying wavelet coefficient and finally is reconstruction. Reconstruction also refers to Inverse Wavelet Transform process. After the filtering process done, CWT has been applied. The analysis of CWT will result scalogram of wavelet coefficients and coefficients line of FECG signal.

3.1 Decomposition

In this task, the selection of appropriate wavelet was very important. The similar wavelet to the desired signal was chosen to the best possible result. Therefore, FECG signal has been decomposed using 5th levels biorthogonal 1.5 wavelets. High Pass Filter (HPF) will produce coefficients, d_n and Low Pass Filter (LPF) will produce approximations, a_n.

Based on Figure 4, the noise at level 4 and 5 are reduced and the signal emphasis on the location of R peak detection. Meaning that, the signal can be detected at frequency band fs/64 –fs/32, with resolution 2016/32 at level 5th, d_5. Where 2016 is the number of samples used, and frequency sampling, f_s is 8 kHz.

For approximation, it results the filtered signal of LPF for each level. It shows that the decomposition process has remove noise at high frequency band. Start at approximation at level 3, a_3 illustrated in Figure 4 shows that the signal is in good condition where the noise has been reduced. At level 5th approximation, a5 LPF, 0 – f_s/64 successfully performs on the signal, and it highlights each peak of the signal which is free from noise.

Although the decomposition process emphasis the location of the peak and remove high frequencies unwanted signal, but FECG signal still difficult to detect. At this stage, the peak amplitude signal can be FECG signal and also noise. Therefore, some modifications on wavelet coefficient need to be done to filter the unwanted peak.

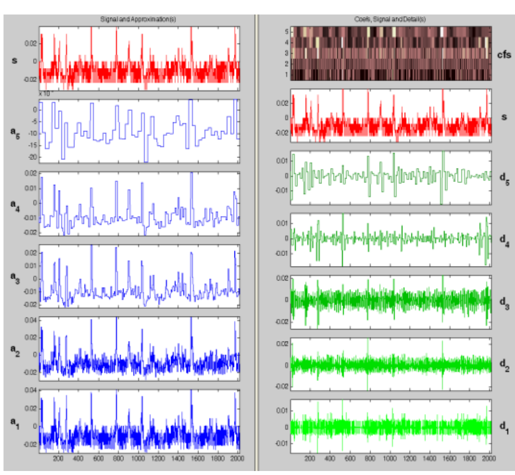

Fig. 4 Detail Coeficient,d_n and approximaion at 5th level of decomposition of FECG signals

3.2 Modifying wavelet coefficient

The next step of de-noising process is modifying wavelet coefficient. Wavelet coefficient can be modified by threshold method. Hard thresholding was used as the wavelet coefficients on some or all scales that are below a certain threshold are believed to be noise and they are set to zero.

Figure 5 shows the threshold process and the result of the process. By using this process, it is very easy to remove the unrelated noisy peak by setting the threshold limit at desired signal. This kind of process is also known as peak detection process and it is very important to FECG extraction.

As in the right bottom of Figure 5, thresholded coefficient shows the detected signal, which is indicated by yellow line after thresholding process was performed. Compared to the original coefficient, it shows a lot of noise and the signals were difficult to detect. The de-noised signal is shown in the right top of Figure 5, in purple line color while, the red color represents the original of the signals.

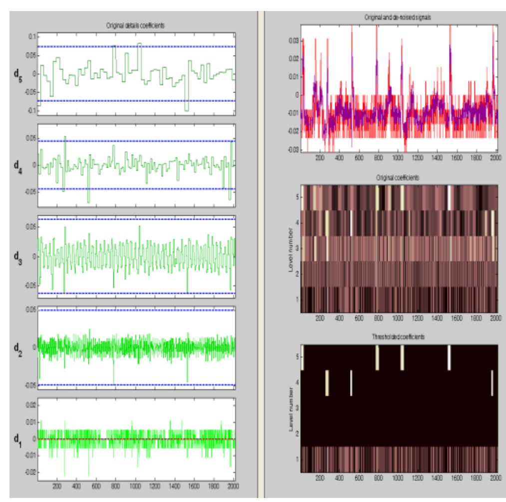

Fig. 5 Thresholding process of FECG signal

3.3 Reconstruction through Inverse DWT

To obtain a de-noised signal, inverse wavelet transform of the thresholded wavelet coefficient need to be performed. This process is also known as reconstruction. By implementing this process, the de-noised signal can be used for further processing.

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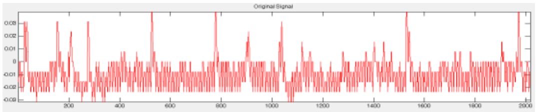
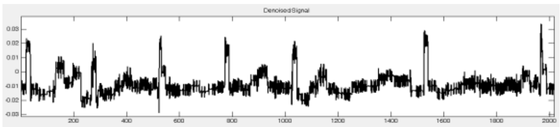
(a)



(b)



(c)

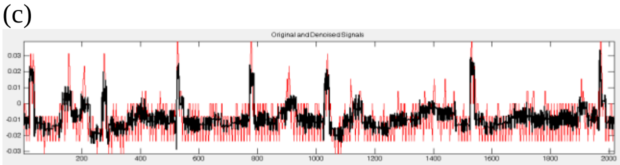


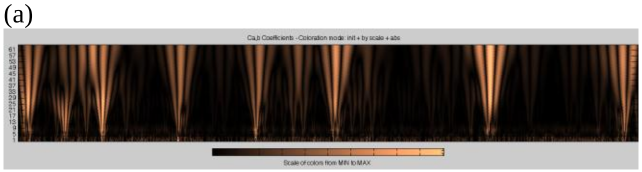
Fig. 6 (a) Original of FECG Signal, (b) Filtered Signal or De-noised Signal, (c) Comparison between original and filtered Signal

Figure 6 show the comparison of the original signal in (a) and de-noised signal in (b). Figure 6 (c) shows the de-noised signal overlap on the original signal. According to these figures, its show that the de-noising process not just increases 3.30dB of SNR, but it is also very useful for peak detection. The chosen of biorthogonal wavelet families was very suitable to filter FECG signal. Furthermore, biorthogonal offered perfect reconstruction that is very useful for obtain the de-noised signal.

3.4 CWT

CWT is very useful in tackling problem involving signal identification and detection of hidden transient (hard to detect, short lived element of signal). By using CWT, the result can be analyzed based on the scalogram. This is more advantageous since it represents the percentage of energy for each coefficient. The brightest part shows that the frequency component is of higher power than with less brighter parts. In addition, it offers user to analyze signals at different scales with different resolutions. Other than scalogram, results of CWT can also be in terms of coefficients line and local maxima lines representation.

(a)



(b)

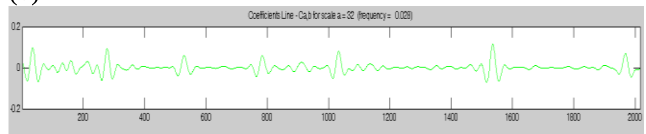


Fig. 7 Result of CWT on abdominal signal position II, (a) Scalogram, (b) coefficient line.

Based on Figure 7, it shows the result of the CWT process on de-noise abdominal signal. Figure 7 (a) shows the scalogram and (b) Coefficient Line. As illustrated in Figure 7 (a), the scalogram emphasizes on the detection of R-peak as shown in maximum resolution of CWT, which is the brightest part. It show that the FECG signal exist in high frequencies than the other detected signals. Even though there are other bright color signal detected, but the intensity of the color are not similar to the regular detected signal. The intensity of the color will represent frequency band for that particular time. Therefore, it can be concluded that the detected signal which is regular in time are in the same frequency band. And it refers to R-peak of FECG signal.

According to the coefficient line, R-peak FECG signals are much easy to be recognized. Each related peak is emphasized and shows the regularity. The unrelated peak can be ignored since it is too small compared to the regular peak. In addition, according to the scalogram, the unrelated peak signals are in detected different frequency band. The coefficient line as illustrated in Figure 7 (b), shows the time representation in frequency 0.028, where FECG signals is detected through CWT.

3.5 Accuracy

To test the performance of R-peak of FECG detection, accuracy (Acc) is calculated before and after wavelet transforms based on formula in [8] and [7]. The formula is calculated based on three quantitative results: true positive (TP) when an R-peak is correctly detected, false negative (FN) when an R-peak was not detected and false positive (FP) when an artifact is detected as R-peak [8]. The Acc calculation indicates the performance of two electrodes biopotential amplifier and processed signals wavelet analysis. Three fetal ECG signal from the same maternal has been recorded and calculated for Acc as in table below.

Table 1: Accuracy Result for FECG detection

Record	Before WT (%)	After WT (%)
1	58.3	78
2	61	88
3	61.5	70
AVERAGE	60.3	78.7

Based on Acc results in Table 1, it shows that average of Acc of FECG detection using the developed device is only 60.3%. Denoising and detection process using WT can increase the accuracy of R-peak detection by about 18.7%.

4.0 CONCLUSION

As there is no standard positioning for FECG detection, two series of experiments have been conducted in order to find the best electrode placement. Misplacement of electrodes sensors will lead to mixed signals between maternal ECG and FECG. After making several measurements, position II is discovered to be the best placement as it is far from maternal ECG and only R-peaks of FECG were detected. FFT proves that strong FECG signals detected stronger than other signals in position II compared to FFT in position I. In position I, FECG was detected as well, but it is mixed with maternal heartbeat. Lots of further process is required to extract maternal ECG, FECG and noise. Though R-peak is detected in position II, there are missing peaks and unwanted peaks. The average accuracy of sensors in FECG detection is a 60.3%.

FECG signals have been decomposed using 5^{th} level, biorthogonal 1.5 wavelets. Through decomposition process, peaks were clearly detected. However, it still mixes desired peaks and unwanted peaks. To highlight the desired peaks and suppress noise, threshold process was implemented. Since noise such as baseline wander and interference are different for each recording, it makes the threshold process unique. Denoise process in wavelet analysis not only reduces common mode noise, but also it can be used to remove unwanted peak. The denoising process contributes 3.30db of SNR. At the end of wavelet analysis, CWT is implemented for detection purposes. As a result, FECG is successfully detected in at frequency of 0.028Hz. Through wavelet analysis, accuracy of FECG detection was improved to 78.7%.

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