Fetal ECG detection
Biomedical Signal Processing 2021

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1 Introduction

During pregnancy it's really important to get as much information as possible about the well-being of the baby, and the fetal electrocardiogram (fECG) is one way to monitor this, because normal ranges for the results of the fetal heart rate analysis can confirm fetal well-being in most of the cases [1].

For a non-invasive recording the electrodes are positioned on the maternal abdomen, this way the signal-to-noise ratio will be relatively low, the main problem is that the maternal ECG (mECG) will interfere with the fetal ECG (but there can be also some breathing or sounds from the digestive system), they will result in a combined signal in the recording [2].

Our main goal is to get the two different sources apart, to separate the fetal ECG from the maternal ECG. For achieving this there are several possible solutions: (1) we can try to separate the signals in the frequency domain, because the frequency of the maternal and fetal heart rate is different: A normal resting heart rate for adults ranges from 60 to 100 beats per minute, while the average fetal heart rate is between 110 and 160 beats per minute, so the heart of a fetus beats noticeably faster than that of its mother.

We can also try to use different signal domains (for example time, frequency, time-frequency) or we can use multiple measurements for the separation.

2 Dataset

We were given two datasets (set-ar and set-b) from The Non-Invasive Fetal ECG Arrhythmia Database. Fetal cardiac arrhythmias are defined as any irregular fetal cardiac rhythm or regular rhythm at a rate outside the reference range of 100 to 200 beat per minute (bpm). Arrhythmias are discovered in about 1% of fetuses with about 10% of these being considered potential sources of morbidity.

Although most fetal arrhythmias are benign, some can cause fetal hydrops and lead to fetal death. This means that up to 1 fetus in 100 need their arrhythmias to be closely monitored and if indicated treated in-utero using antiarrhythmic therapy.

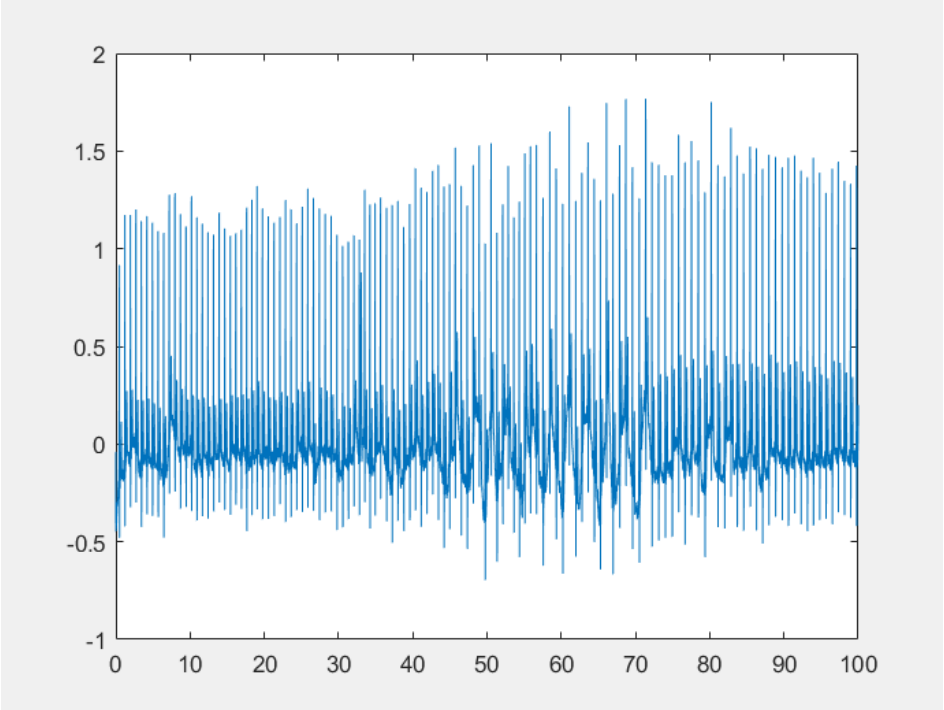

Figure 1: Original ECG

The first set of data (set-ar) provides a series of fetal arrhythmias recordings (n=12) and a number of control normal rhythm recordings (n=14) performed using the non-invasive fetal electrocardiography (NI-FECG) technique. For each recording, a set of four or five abdominal channels and one chest maternal channel were recorded as the example in Fig1. The sampling frequency was 500 Hz or 1 kHz.

3 Methods

At first we started with examining and plotting the data, and also created the histogram of the signal to see its distribution. After that we tried to separate the fetal and mathernal ECG with Independent Component Analysis, and used the Pan Tompkins Algorithm for the detection of the QRS complexes.

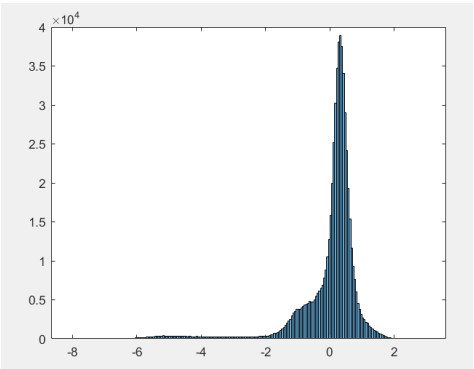

Figure 2: Histogram

3.1 Principal Component Analysis (PCA) and Independent Component Analysis (ICA)

PCA and ICA are two popular non-adaptive signal processing methods that are widely used in processing the mother's abdominal electrocardiogram (ECG) signals to extract the fetal ECG (fECG) [4]. The main preprocessing step for ICA is (pre)whitening. We used prewhitening by performing the singular value decomposition of the covariance matrix.

By using components from the result after the process of ICA, using covariance to separate the mother and fetal signal was the first idea. Since these signals have different covariance, finding the peaks of the mother's ECG was the first step. However while we are searching for the peaks in the maternal ECG the minimum distance would be double of the fetal peaks minimum distance due to the rate of it being nearly the double of the maternal ECG.

As a second step we applied window reduction on the mixed signal to get rid of the mother's signal (Fig3). So, the remaining signal peaks were the peaks of the fetal ECG (Fig4). To explain seperation of the signal thoroughly, using variance of the mother and fetal signal was very tricky. Due to having some common covariances we had to choose the smallest variance and not the same with the mother signal's variances to be able to select the right channel to pick the peaks.

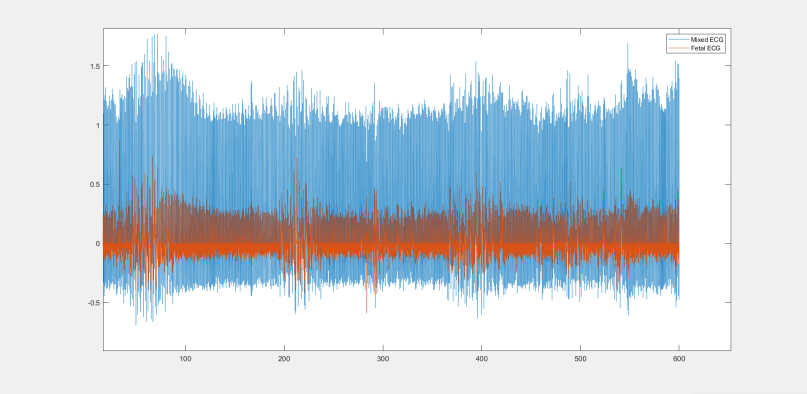

Figure 3: Fetal and mixed ECG: widened

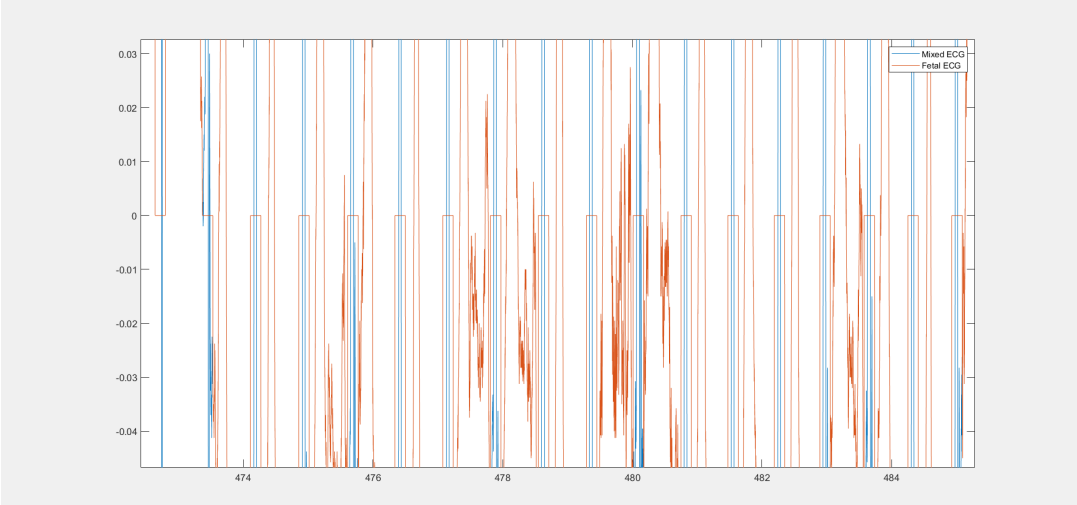

Figure 4: Fetal and mixed ECG: zoomed

3.2 Pan Tompkins algorithm

The Pan Tompkins algorithm can be used to detect the QRS complex in an ECG signal. It applies a series of filters to highlight the frequency content of this segment and removes the background noise. In the second step it squares the signal to amplify the QRS contribution, so the QRS complex would be easier to find. At the last step it uses some adaptive thresholds to detect the peaks of the filtered signal.

As the first step of the algorithm we used a 3rd order bandpass Butterworth filter, with a cutoff frequency of 6-42 Hz to get rid of the noise. We checked each channel using a for loop, and applied the Butterworth filter, then performed zero-phase digital filtering with filtfilt. After that we got the envelope to select the peaks more easily since it has more obvious peaks than other steps. Finally we used findpeaks to locate the peaks of the fetal ECG. We tried different values for MinPeakProminence, MinPeakDistance, MinPeakHeight and Threshold, but we got the best result with these values:

Parameter	MinPeakProminence	MinPeakDistance
Mother	mean(abs(sig))*1.5	0.4*fs
Fetal	mean(abs(envelopefetal))*2	0.2*fs

Table 1: Best resulted parameters for findpeaks function

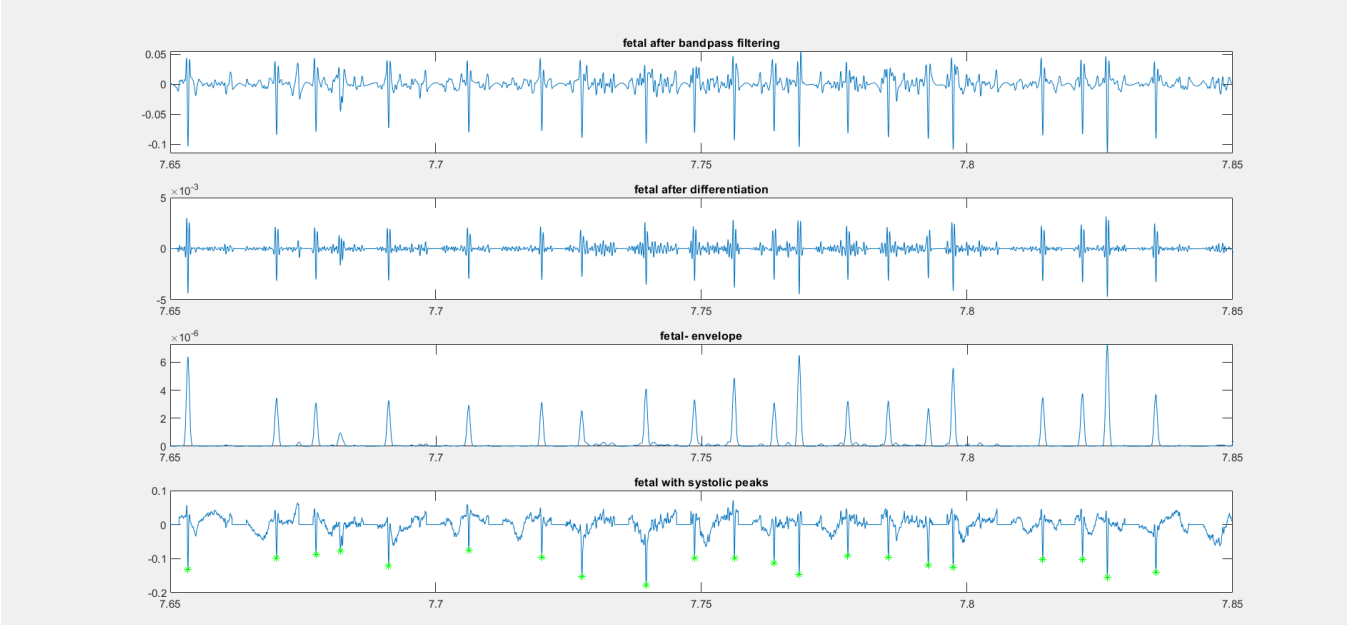

Figure 5: Pan Tompkins algorithm results

4 Results

So basically, since we have the fetal signal, we can get the peak locations by using Pan Tompkins method as we did in the assignment 5. Additionally, after we have the fetal peak locations, we can get the QT interval.

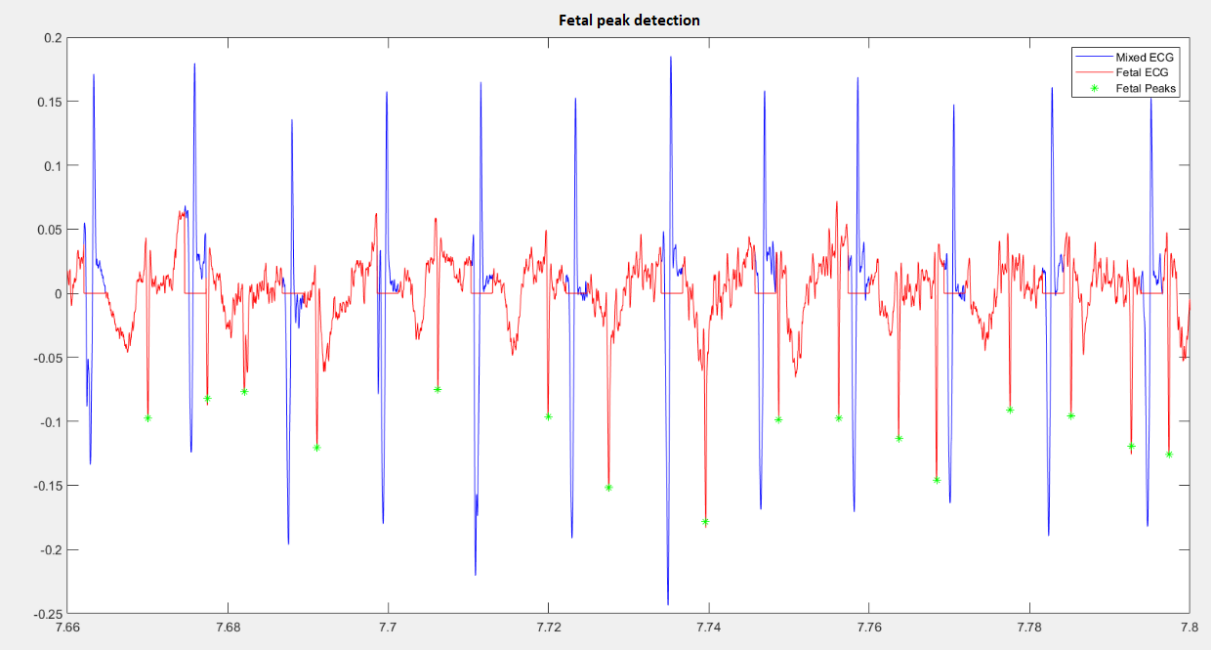

Figure 6: Mothers ECG, Fetals ECG, Peak points for Fetal ECG

Using these methods we could separate the fetal ECG-s and detect the QRS complex in some of the samples, although there were other samples that remained mixed with the maternal ECG, so the fetal peak detection didn't work well on them especially on chest channel as we can see Fig.8.

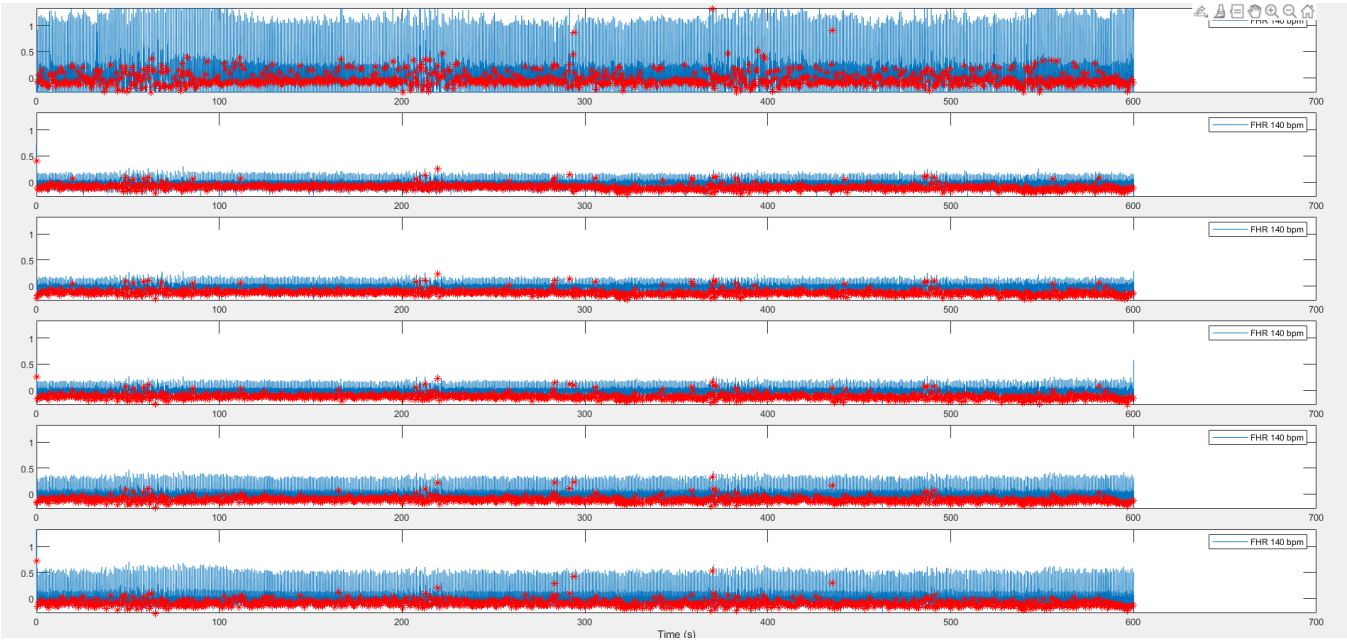

Figure 7: Fetal peaks in the mixed ECG signal:widened[0 700]

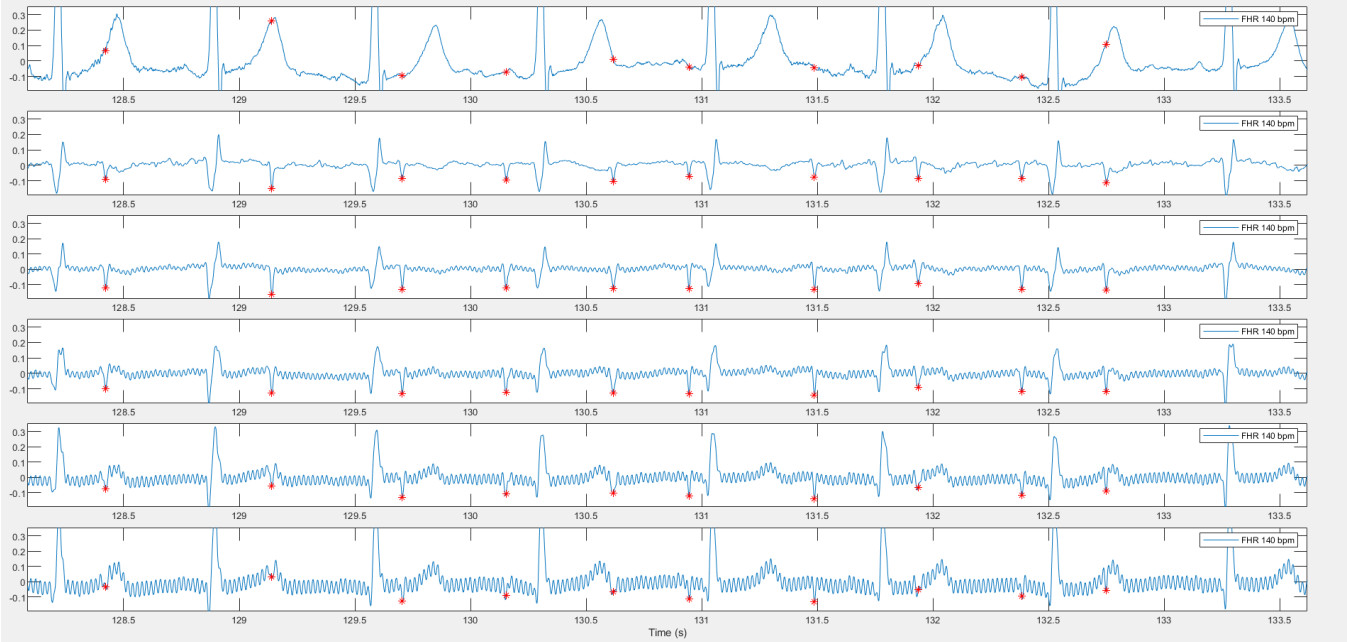

Figure 8: Fetal peaks in the mixed ECG signal:zoomed[128.5 133.5]

References

[1] Adam Matonia, Janusz Jezewski, Tomasz Kupka, Michał Jezewski, Krzysztof Horoba, Janusz Wrobel, Robert Czabanski Radana Kahankowa: Fetal electrocardiograms, direct and abdominal with reference heartbeat annotations (2020)

[2] R Vullings 1, C Peters, M Mischi, G Oei, J Bergmans: Maternal ECG removal from non-invasive fetal ECG recordings (2006)

[3] Mansi Ghodsi, Hossein Hassani, Saeid Sanei: Extracting fetal heart signal from noisy maternal ECG by multivariate singular spectrum analysis (2010)

[4] Comparative Effectiveness of ICA and PCA in Extraction of Fetal ECG From Abdominal Signals: Toward Non-invasive Fetal Monitoring