FETAL QRS-COMPLEXES DETECTIONS IN ABDOMINAL SIGNAL BY USING WAVELET-BISPECTRUM

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Summary. Fetal hypoxia or distress is a physical stress experienced by a fetus due to a lack of oxygen. Intrauterine hypoxia and the resultant perinatal brain damages may lead to extraordinary effects, including continuous lifelong treatments. One of the ways for detecting symptoms of hypoxia is monitoring of the fetus heart activity. At present, the basic method of monitoring the condition of unborn baby is the ultrasound cardiotocography (CTG). Considerably more information for early detection of the fetal hypoxia may be obtained by analyzing fetal electrocardiogram (FECG).

Keywords: FECG; NI-FECG; wavelet-bispectrum; abdominal signal; QRS-complexes;

Up to 30% of women have complications during pregnancy. The most common and serious disease is fetal hypoxia - physical stress that the fetus experiences due to lack of oxygen. One way to detect hypoxia is to measure fetal heart activity. Currently, the main method of monitoring the fetal heart is Doppler ultrasound and
cardiotocography (CTG). But ultrasound technology is not completely safe and non-invasive because it involves triggering ultrasound radiation towards the fetus. In addition, CTG provides low accuracy in measuring the fetal heart rate. An alternative to current technology is non-invasive fetal ECG (NI-FECG) or abdominal ECG [1]. Non-invasive and long-term monitoring of these signals can be performed using electrodes placed on the abdominal wall of a pregnant woman. However, the low amplitude of the fetal ECG and abdominal interventions are the limiting factors of this method. In accordance with the known structure, the processing of the abdominal signal consists of several stages.

In most cases (when assessing the functional state of the fetus by the parameters of its heart rate), the end result of processing is only the heart rate of the fetus (and mother). The ECG morphology is not important in this case. The theory of estimating the parameters of signals observed against a background of noise usually indicates that the more observations (the number of channels) and the smaller the number of parameters estimated from these observations, the better the quality of estimates [1].

Therefore, the first and main stage of processing is working with rhythm only. Algorithms and processing parameters in this case should provide the best ECG extraction and measurement of rhythm parameters.

a) Pre-filtering. Studies show [2] that the best quality of ECG extraction (in practice against the background of real abdominal murmurs) is provided in the 15–100 Hz range, although the ECG shape is disturbed. The default cutoff frequency is 16 Hz for high pass filters.

b) Extraction of the ECG from the abdominal signal can be done in various ways. An ICA-based approach is used. In a program, these are JADE or SOBI (optional, offline processing mode) and RunICA (in write mode). The use of ICA (for a sufficiently large number of channels) allows one to obtain the advantages of space-time processing [3] (spatial accumulation of the useful signal component and separation of correlated interfering signals into separate components).

c) ICA-based extraction algorithms work much better if the MECG component is removed from the abdominal mixture. In the simplest case, by subtracting the ECG template. This can be done both in the space of the original abdominal signals and in the space of the components. This is done by going to the component area with πCA. In each significant MECG component, the template is formed and subtracted, the remainder in the MQRS domain is filtered using a wavelet filter. This allows the R-peaks of the ECG to be retained when superimposed on the ECG.

d) The ICA procedure is applied to the remote ECG signal. The mixing matrix is determined over a short training interval (default 30 seconds) and then applied to the entire recording (this is a flaw in the algorithm, if the signal is long, the mixing conditions may change, but it usually works well.). By default, the definition of the mixing matrix is made in the initial part of the recording, but it is possible (manually) to select any part. In some cases, this significantly improves the quality of the extraction. After the completion of the ICA procedure, the channel with the FECG component is automatically detected.

e) The Pan-Tompkins algorithm is applied to the automatically determined channel with the FECG component to determine the fQRS positions.
However, this approach does not provide position detection at low signal to noise ratio (SNR) values and at low FECG amplitude. Therefore, the goal of this work is to create a new algorithm that will replace the Pan-Tompkins algorithm for determining the positions of fQRS complexes in the extracted FECG from the abdominal signal, which will allow the allocation of positions at lower SNR values based on wavelet-bispectrum.

In particular, the wavelet-bispectrum of the signal can be defined as [4]:

\[ B_W(f_1, b) = \int W^*(f_3, b) W(f_2, b) W(f_1, b) \, db \]  \hspace{1cm} (1)

By the definition given in [4], a continuous wavelet transform of some signal \( f(x) \) has the following form:

\[ W_\psi(a, b) = \frac{1}{\sqrt{c_\psi}} \int f(x) \psi_{ab}^*(x) \, dx \]  \hspace{1cm} (2)

where:

\[ \psi_{ab}(x) = \frac{1}{\sqrt{a}} \psi\left(\frac{x-b}{a}\right) \]

\( a \) and \( b \) are the scale and shift, respectively; \( \psi \) is the wavelet-forming function.

The wavelet bispectrum (1) can serve as a measure of the phase coupling in the time interval \( T \), which manifests itself between the components of the wavelet spectrum at frequencies \( f_1, f_2, f_3 \). If the phases of one of the three spectral components are the sum or difference of the other two, the wavelet bispectrum will show a significant value.

Thus, the wavelet bispectrum has a nonzero result only when the phases of the three frequencies are related. It can be expected with a high degree of probability that this property should manifest itself in the presence of phase bonds in complex dynamic biomedical signals of the ECG type.

The result of applying the signal splitting procedure into independent components (d) and result of Pan-Tompkins transform (e) for detection of fetal QRS-complexes was presented (fig. 1 - fig. 2).

![Multi-channel abdominal ECG after signal-decomposition](image-url)

**Fig. 1. Result of the ICA procedure to the remote ECG signal**
Fig. 2. **Result of Pan-Tompkins transform and fQRS-detection**

The real position of the fetal QRS-complexes was presented (fig. 3).

Fig. 3. **Real position of fQRS-complexes**

As seen in figures 2 and 3, this approach did not accurately locate the fetal QRS complexes. This is due to the low signal-to-noise ratio, as well as the low amplitude of the QRS complexes themselves. The result of applying the wavelet-bispectral transform to the automatically selected fetal ECG after the procedure of signal decomposition into independent components was presented on 3D view (fig. 4) and front view (fig. 5).

Fig. 4. **Wavelet-Bispectrum transform of fetal ECG after signal-decomposition (3D view)**
The last step is the application of the Pan-Tompkins procedure to the wavelet bispectrum to determine the positions of the fetal QRS complexes (fig. 6).

Conclusions. As can be seen from the results presented in Figure 6, the approach based on the wavelet bispectrum allows more accurate determination of the location of the fetal QRS complexes at the extracted fetal ECG after the procedure for separating the signal into independent components (ICA) at lower amplitudes of fetal ECG and a low value of signal-to-noise ratio. This approach is not a replacement for the standard algorithm, but is only an addition to it, which can be used in limited cases when the standard approach did not give a result. The experimental results were carried out on real abdominal signals recorded in the perinatal centers of Kharkov [5] – [6], as well as on signals taken from the open PhysioNet database. Also, during the experiments, artificially synthesized abdominal signals were used using an abdominal signal generator [7].

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