RECOGNITION OF PREMATURE BIRTHS BY BISPECTRUM-BASED ABDOMINAL ELECTROMYOGRAPHY SIGNAL PROCESSING

***O. Viunytskyi*[1]*, V. Shulgin*[1]*, A. Totsky*[1]*, K. Egiazarian*[2]*, Senior Member IEEE, O. Polotska*[3]**

[1]*National Aerospace University, Department of Information and Communication Technologies named after O.O. Zelensky, Chkalova Str. 17, 61070, Kharkov, Ukraine, Telephone: + 38 057 7884352, E-mail: Leshauhrin@gmail.com; Vyacheslav.Shulgin@gmail.com; o.totskiy@khai.edu*

[2]*Tampere University of Technology, Department of Signal Processing, P. O. Box 553, FIN-33101, Tampere, Finland, Telephone: +358 3 3115 2923, E-mail: karen.egiazarian@tut.fi*

[3]*V.N. Karazin Kharkiv National University, English Language Department, Svobody sq., 4, Kharkov, 61022, Ukraine, E-mail: engldpt@karazin.ua*

A novel technique for detection and recognition of normal and premature births is suggested and experimentally examined. The technique proposed in this paper is based on the extraction of novel class of informative features contained in higher-order spectrum namely bispectrum of the abdominal electromyography signals registered on the abdominal surface of pregnant woman. It is demonstrated that the amplitude bispectrum, phase bispectrum and bicoherence signatures computed for electromyography signals can serve as the perspective facilities for detection and recognition of normal and premature births. Suggested bispectrum-based information features were studied by real-life experimental data processing. Uterine activity corresponding to two weeks and one week before birth for several patients has been investigated. Experimental results obtained for a number of the patients demonstrate the possibility to extract novel kinds of classification features contained in the computed biamplitude, biphase and bicoherence signatures.

KEY WORDS: *monitor the health, biomedical data processing, normal and premature birth, uterus, uterine activity, abdominal electromyography signal, bispectrum, biphase, bicoherence*

1. INTRODUCTION

Currently, the approaches, techniques and algorithms that were developed and currently used for digital signal and image processing find novel applications. Exploiting these techniques and algorithms for biomedical data processing has already become promising tool for solving various diagnostic and monitoring problems related to vital human indices, as well as they stimulate creating new technologies and devices for application in modern medicine. The vast majority of existing medical diagnostic systems are designed to monitor the health status of the adults, and less often used to monitor the health of children. However, nowadays, there are no technologies and systems designed for jointly monitoring at the same time the state of mother and fetus during the pregnancy. This situation should be considered as a serious drawback of modern medical diagnostics. It should be stressed that future human health, including the costs of maintaining it throughout the life contains in the womb. At the same time, with an increase in the average age of those giving birth, the number of pregnancies with complications considerably increased. The miscarriages, premature birth, delays in labor, and fetal hypoxia provoke the health problems in the child's future life. Moreover, this trend is observed in not only countries with insufficiently developed health care system but also in developed countries, such as the USA, Germany, Great Britain, and France [1] – [5].

Therefore, design of new methods, technologies, and systems that implement them to monitor the health and fetal development of the fetus and the mother is an important problem of modern medical diagnostics. New software and equipment designed for non-invasive observation of the fetus during pregnancy and based on analysis the multichannel signals registered on the abdominal surface of the pregnant woman are represented in [6] – [8]. Results of preliminary study related to exploiting the data contained in a multichannel abdominal signal for measurement the level and parameters of contractile uterine activity, as well as evaluating changes in intrauterine pressure are obtained and analyzed in [9].

Recently, in order to detect preterm labor, various techniques were examined as follows: by measurement of biochemical markers; by using clinical diagnosis that is based on evaluation of cervical dilatation, bleeding, or rupture of the membrane; by measurement of mechanical contractions of the uterus; intrauterine pressure measurement using catheter; by abdominal and transvaginal ultrasound investigations; by electromyography of the uterus or electrohysterography; as well as by magnetomiography.

Nowadays, the strategy exploiting electrohysterography diagnostic is accepted as one of the most promising approach by great number of the researchers. Electromyogram diagnostic is based on the electrical activity of smooth muscle cells of the uterus and corresponding mechanical activity. External electromyogram of the uterus (EMG, EHG) is the result of measurement of the electrical potentials registered on the abdominal surface of the pregnant woman. This makes EHG as a good marker of uterine activity [5].

Distinctive feature of this paper is the predicting of premature births by analysis of bispectrum-based signatures computed for electromyography signals registered on the abdominal surface of a pregnant woman. Bispectrum, in opposite to the well-known energy spectrum, allows not only evaluating the statistical properties of a process under study more profoundly but also extracting novel information features such as the contributions caused by phase coupling [10]. Bispectrum-based strategy can serve as a promising tool for detection and eliciting information related to interactions between spectral components and phase coupling. Moreover, low sensitivity of bispectrum to additive white Gaussian noise (AWGN) also must be considered as the evident benefit. Invariance property of bispectrum to random signal delays gives very useful possibility for coherent accumulation and averaging noisy weak bispectral estimates registered simultaneously by number of sensors in order to smooth noise contributions. Therefore, bispectrum-based signal processing is able providing detection and extraction phase coupling and discriminating phase coupled spectral contributions from those that are not. In addition, signal processing based on the bispectrum provides suppression of the contributions caused by random motion artifacts and additive Gaussian noise.

This paper is organized as follows. In the following Sections, suggested bispectrum-based strategy exploited for processing abdominal signals is described and experimentally studied.. Finally, the conclusions that can be drown from this investigations are given.

2. DESCRIPTION OF SUGGESTED METHOD

Let us consider practical initial conditions existing for registration the electrohysterogram signals from the abdominal surface of a pregnant woman. For this purpose, the array of the sensors shown in Fig. 1 is used. The dataset used for the study in this work are taken from the open access database "Icelandic 16-electrode Electrohysterogram (EHG) Database". The hardware contains 16 sensors that simultaneously read the signals from the abdominal surface of a pregnant woman.

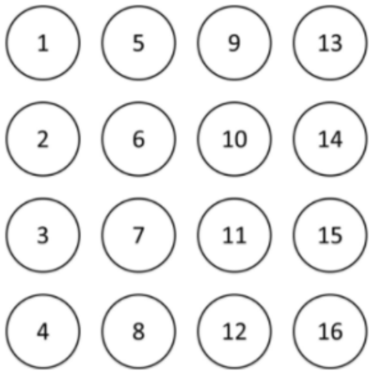

Fig. 1. Array of the sensors

Electrohysterogram signal corresponds to one of the contributions contained in the multi-component abdominal signal including EHG, mixture of the electrocardiographic signals of mother and fetus (ECGP and ECGM), the respiratory contribution, and various interference contributions including AWGN. Example of 16-channel signal record of duration equal to 4000 seconds is demonstrated in Fig. 2. Signal extracted from one single processing channel during time interval of twenty five seconds is shown in Fig. 3.

In order to exclude third-party interference contributions and extract only the EHG component, band pass filtering has been accomplished. This filter is tuned to the frequency bandwidth of 0.3…0.8 Hz. Such strategy provides removing the mother’s heartbeat component contributions, as well as the mother’s respiratory components, the fetal heart contraction components. As a result, only the components of the uterine activity, and the components caused by fetal movement inside the womb are extracted. The result of the filtering is shown in Fig. 4.

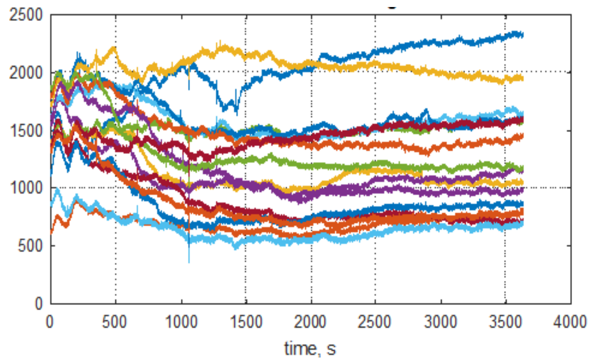

Fig. 2. Example of the record of 16-channel abdominal signal

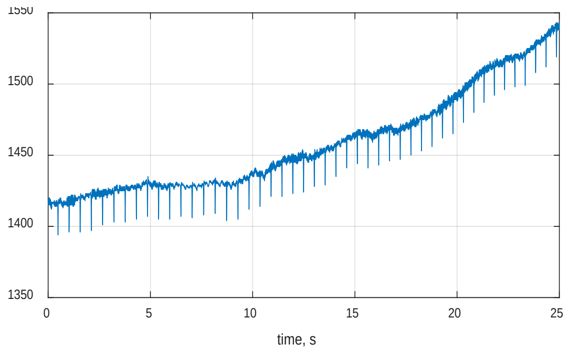

Fig. 3. Single abdominal signal

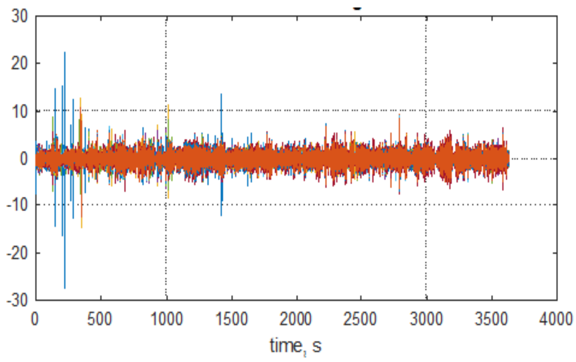

Fig. 4. Result of low pass filtering

The files contained in the above mentioned database are arranged as follows: by temporal positions of possible bursts of uterine activity, bursts of uterine activity, and fetal movement indication. Time fragments of the EMG signals possibly and definitely contained uterine activity are represented in Fig. 5 and Fig. 6, respectively.

As can be seen from Fig. 4 and Fig. 5, the behavior of the uterus activity is spatially distributed slowly on the abdominal surface of a pregnant woman. Hence, the signals in different channels are shifted relatively to each other. Modern algorithms [8] provide estimation of this signal shifts and evaluation the speed of propagation of the uterine excitation signal along the surface of the abdominal. The latter parameter commonly serves for estimation of the prediction of premature birth.

When the birth is approaching, the uterus begins to shrink more actively, and the speed of the uterine excitation signal increases. Then, the mutual shifts in each channel are eliminated, and after that the signals are coherently averaged and the energy of the formed signal is evaluated. Signal energy is the second parameter commonly used for estimation of the probability of premature birth. Decision making is usually accomplished in the following form: more signal energy more possibility of premature birth [8]. However, in the latter approach, final result largely depends on the input signal-to-noise ratio (SNR), and lower SNR worsen result of signal coherent averaging, and, therefore, worsen probability of recognition of premature birth. The latter drawback stimulates the researchers to seek novel signal processing techniques operating in low SNR environment and providing extraction of robust recognition features. In this paper, novel bispectrum-based signal processing strategy is developed for premature birth recognition. Extracting the robust recognition features is implemented from biamplitude, biphase, and bicoherence signatures. As compared with common energy-based strategy, we hope that evaluation of phase coupling will give novel perspective view for the diagnostic of premature birth recognition.

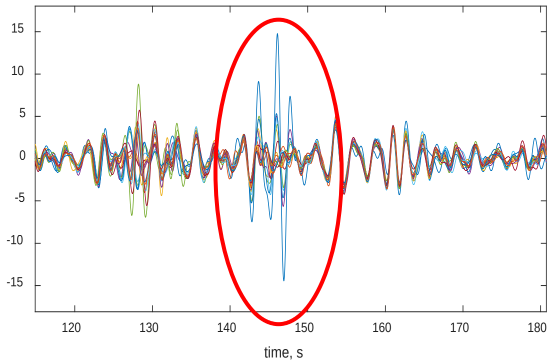

Fig. 5. Possible uterine activity

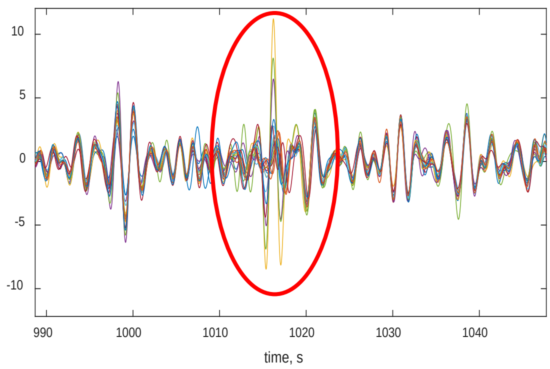

Fig. 6. Example of uterine activity

Suggested in this paper approach is based on bispectral analysis of the abdominal signals provoked by active movement of uterus. Bispectrum estimate $\hat{B}_i(p,q)$ computed for abdominal signal registered by arbitrary *i*-th sensor can be written as

$$\hat{B}_i(p,q) = \hat{S}_i(p)\hat{S}_i(q_2)\hat{S}_i^*(p+q) \quad , \qquad (1)$$

where $\hat{S}_i(...)$ is the Fourier transform computed for signal under study; *p* and *q* are the frequency indexes; symbol * denotes complex conjugation.

Complex-valued bispectrum estimate $\hat{B}_i(p,q)$ (1) can be expressed in the form of

$$\hat{B}_i(p,q) = \left|\hat{B}_i(p,q)\right| \exp[j\hat{\varphi}_i(p,q)] \quad , \qquad (2)$$

where $\left|\hat{B}_i(p,q)\right|$ is the amplitude bispectrum estimate (biamplitude), $\hat{\varphi}_i(p,q) = \mathrm{arctg}[\mathrm{Im}(\hat{B}_i(p,q) / \mathrm{Re}(\hat{B}_i(p,q)]$ is the phase bispectrum estimate (biphase), $j = \sqrt{-1}$.

Both amplitude and phase bispectra makes it possible to extract and estimate the phase coupling contributions existing in the signals under study. These contributions carry information about premature birth. Note that important peculiarity of phase bispectrum is the invariance to the amplitude of the input signal that can vary within large limits.

Bicoherence b(*p*,*q*) is a value that serves as a quantitative measure for evaluation the phase coupling existing between spectral components in the signal under study. Bicoherence can be written in the form of

$$b_i(p,q) = \frac{|\hat{B}_i(p,q)|^2}{P_i(p)P_i(q)P_i(p+q)} \quad , \qquad (3)$$

where $P_i(\ldots)$ is the power spectral density.

Bicoherence (3) tends to zero in the case of no phase coupling. For instance, for AWGN bicoherence value tends to zero. It means that for the interference like AWGN, exists no phase coupling.

3. COMPUTER SIMULATIONS RESULTS

Since the temporal locations of the uterine activity in the EMG signal are known, it is necessary to evaluate bispectrum estimates for corresponding time intervals. The bispectrum estimates were computed by formula (1) for each of sixteen channels. Consequently, sixteen bispectra according to the number of the sensors were computed for single burst of uterine activity. The next data processing step is coherent ensemble averaging of sixteen complex-valued bispectra (1). This procedure makes it possible to isolate as much as possible from the noise components only those contributions of the spectral components that have certain frequency-phase relationships, i.e. those spectral components that are phase coupled. These components are related only to the uterine activity. Recorded EMG signals contains several bursts caused by activity of the uterus. For each burst the data processing procedures described above is performed. Sixteen bispectra computed for each separate burst are averaged among themselves. In the final data processing step, there is only averaged bispectrum, which will be used to make decision about possible normal or premature birth.

Number of the patients were examined for uterine activity evaluation and testing. The testing was performed for two weeks and one week before the birth. Below, biamplitude, biphase and bicoherence signatures computed according to (2) and (3) are represented, respectively. Biamplitude signature of uterine activity for the first patient who gave birth on the thirty-seventh week is shown in Fig. 7. The abdominal signal was recorded by two weeks before birth.

Biamplitude signature of uterine activity corresponding to one week before birth for the same patient is shown in Fig. 8.

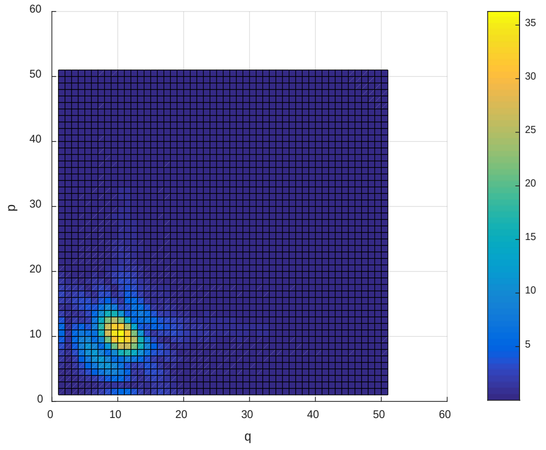

Fig. 7. Averaged amplitude bispectrum of uterine activity for the first patient.

Two weeks before the birth

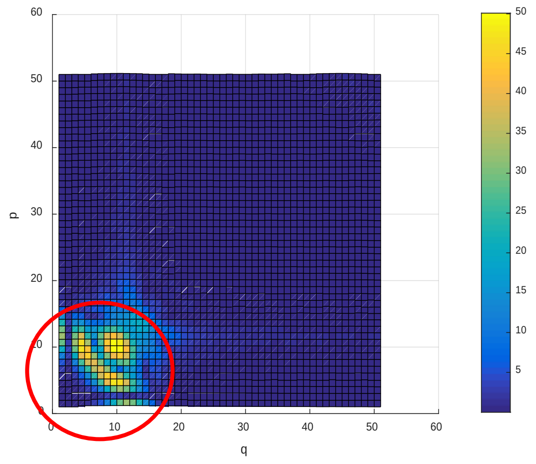

Fig. 8. Averaged amplitude bispectrum of uterine activity for the first patient.

One week before the birth

The biphase signature computed for the first patient for two weeks before birth is represented in Fig. 9. Biphase signature computed for one week before the birth is represented in Fig. 10.

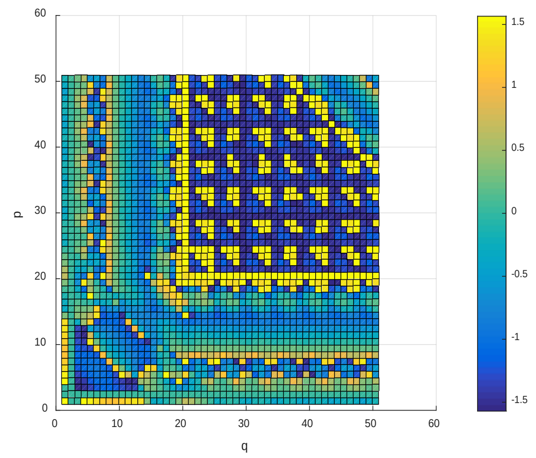

Fig. 9. Phase bispectrum of uterine activity for the first patient. Two weeks before the birth

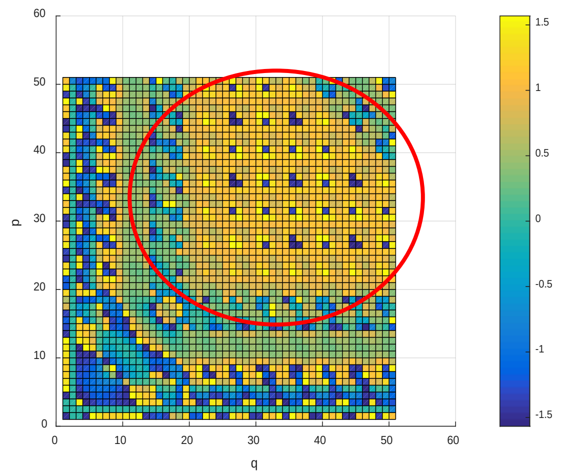

Fig. 10. Phase bispectrum of uterine activity for the first patient. One week before the birth

As can be clearly seen from Fig. 8, two evident contributions in the form of two peaks at the frequencies of 3 Hz and 10 Hz appear in the biamplitude signature. It should be stressed, that these contributions were absent in the biamplitude signature registered for two weeks before birth. In addition, it can be stressed that the biamplitude value has increased by a third. Therefore, biamplitude can serve as sensitive feature for detection of premature birth.

As can be seen from comparison of Fig. 9 and Fig. 10, the biphase values were changed by 180 degrees. It can serve as indicator for detection of the premature birth.

Bicoherence signatures computed for the first patient for two weeks and one week before birth are shown in Fig. 11 and Fig. 12, respectively.

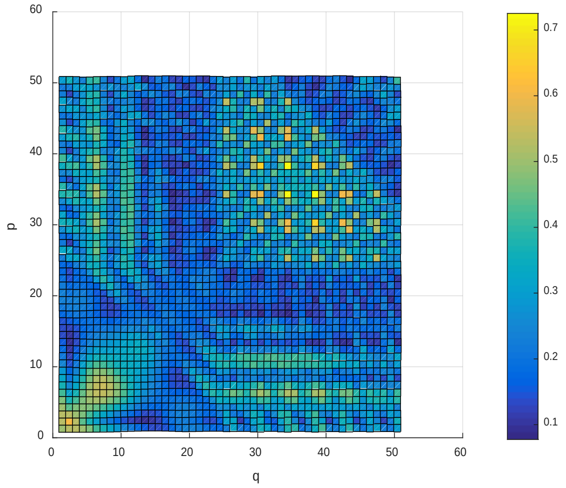

Fig. 11. Bicoherence of uterine activity for the first patient. Two weeks before the birth

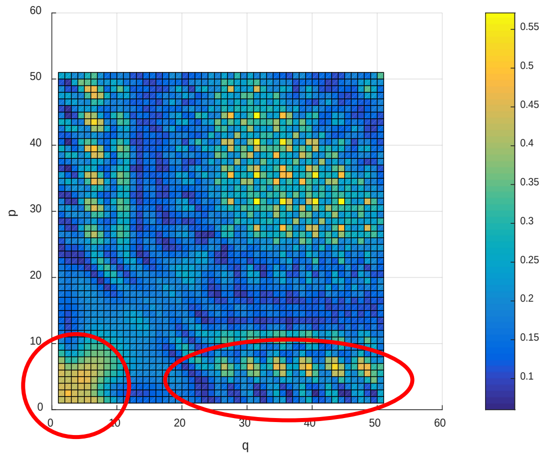

Fig. 12. Bicoherence of uterine activity for the first patient. One week before the birth

It is seen from Fig. 12 that new peak contributions appear in the bicoherence signature at the high frequencies from 25 Hz till to 50 Hz. In addition, it is also seen that at low frequencies range of

0…10 Hz, the area containing phase coupled spectral components become wider along the frequency axis. Thus, we can find some classification features that will be able indicate the approach of birth.

It is necessary to check whether they will prove themselves for other patients. We take the second entry for the other patient and will accomplish the same study.

Biamplitude signature corresponding to uterine activity for the second patient who gave birth on the thirty-fifth week is shown in Fig. 13. The abdominal signal was recorded on the thirty-third week, i.e. for two weeks before birth. Biamplitude signature for nine outbreaks of uterine activity for the same patient is shown in Fig. 14. Corresponding abdominal signal was recorded on the thirty-fourth week, i.e. by one week before birth.

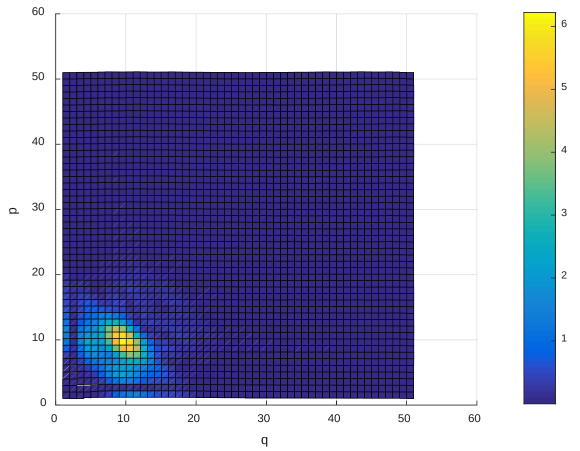

Fig. 13. Averaged amplitude bispectrum of uterine activity for the second patient.

Two weeks before the birth

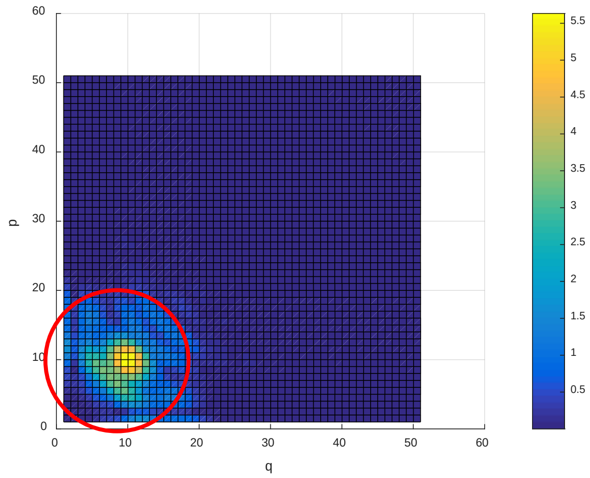

Fig. 14. Averaged amplitude bispectrum of uterine activity for the second patient.

One week before the birth

As can be seen from Fig. 14, the peaks at the frequencies of 3 Hz and 10 Hz are appeared. It is important to note that these peaks were absent for two weeks before birth. Despite these peaks have smaller amplitudes than for the first patient, they can be considered as evident classification features.

Biphase signatures computed for the first patient for two weeks and one week before birth are demonstrated in Fig. 15 and Fig. 16, respectively.

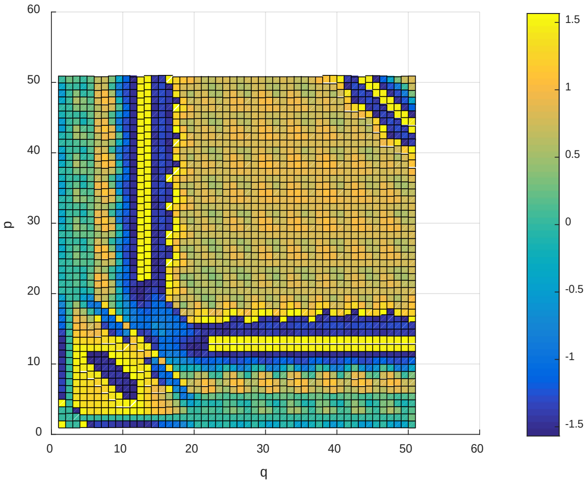

Fig. 15. Phase bispectrum of uterine activity for the second patient. Two weeks before the birth

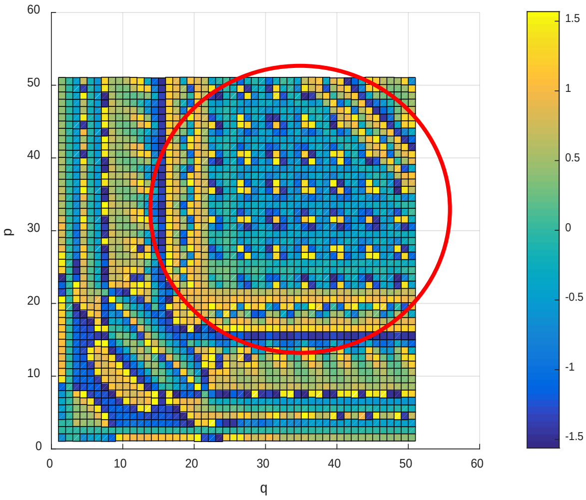

Fig. 16. Phase bispectrum of uterine activity for the second patient. One week before the birth

As can be seen from comparison between Fig. 15 and Fig. 16, the phase values in the biphase signature were changed by 180 degrees. For the first patient, the phase changes are of opposite values. Under considered case, the phase has changed from + $\pi/2$ to -$\pi/2$. Therefore, biphase-based feature can be considered as a rather sensitive tool for diagnostics and its usage can give different results for different patients.

Bicoherence signatures computed for the first patient for two weeks and one week before birth are shown in Fig. 17 and Fig. 18, respectively.

It can be seen from Fig. 18 that some new spectral components are appeared within the frequency range from 25 Hz till to 50 Hz for a week before the birth. It is also seen that new phase coupled spectral components also appeared at low frequencies at the range of 0…10 Hz. As well as for the first patient, the main difference between the records for two weeks and one week in the bicoherence domain is the appearance of new phase coupled spectral components at high frequencies.

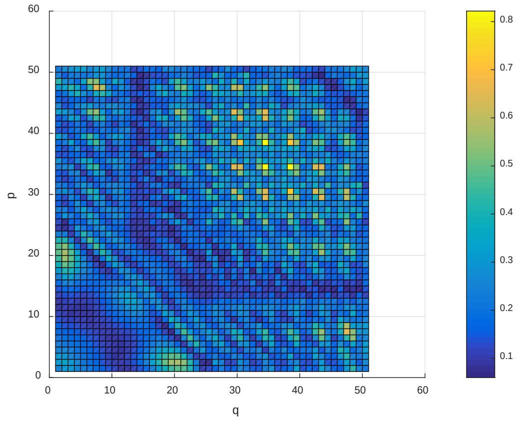

Fig. 17. Bicoherence of uterine activity for the second patient. Two weeks before the birth

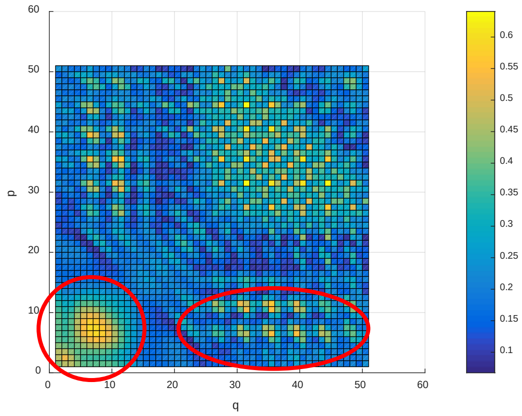

Fig. 18. Bicoherence of uterine activity for the second patient. One week before the birth

4. CONCLUSIONS

In this paper, a novel diagnostic technique was presented and examined for detection and prediction of normal or premature births. In order to implement and test suggested technique, abdominal signal records contained in the open access database "Icelandic 16-electrode Electrohysterogram (EHG) Database" were used. This database allows accessing to sixteen-channel signal records registered on the abdominal surface of the pregnant women. Statistical analysis was accomplished for more than 100 records of abdominal signals for various patients. Treatment was performed for patients who gave birth before 37 weeks and for those who gave birth after 37 weeks. The treatment was performed for the signals related to both two weeks before the birth and one week before the birth.

To remove the extra interference components that are contained in the source records (EHG, electrocardiographic signals of the mother and fetus (ECGP and ECGM), the respiratory component, and various interference components), band pass filtering within the frequency range of 0.3 … 0.8 Hz has been performed.

This frequency band was selected due to *a priori* knowledge that the components of the uterine activity are concentrated within the frequency band of 0.3…3 Hz. At the same time, the ECGP components are contained at the frequencies of 1 Hz. Hence, after filtering within the band of 0.3…3 Hz we would have to develop algorithms for additional ECGP filtering. Selection of the band of 0.3…0.8 Hz allows one to suppress the ECGP component completely without considerable distorting the components of the uterine activity. Possibility of premature birth prediction has been demonstrated by information feature extraction both from amplitude and phase bispectrum, as well as bicoherence signatures computed for real-life EMG signals. Four novel bispectrum-based types of classification features were obtained as follows.

First, it has been demonstrated the appearance of novel classification features within frequency range of 3…10 Hz in biamplitude domain for a patient of one week before the birth. Second, appearance the phase value changes by π in the phase bispectrum has been observed for a week before relatively to the phase bispectrum computed for two weeks before the birth. These changes were detected in the high-frequency domain. Third, it can be noted appearance the classification contributions in bicoherence signatures observed in the low-frequency range from 0 to 10 Hz as compared with bicoherence values computed for two weeks before the birth. Fourth, it should be stressed the appearance of new spectral components in the bicoherence signature in the high-frequency region from 25 Hz to 50 Hz.

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