FETAL MONITORING WITH ONLINE PROCESSING OF ELECTROCARDIOGRAPHIC SIGNALS

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Abstract: Conventional fetal monitoring for recognition of fetal distress is based on ultrasound Doppler technique. A new approach proposed in this work relies on analysis of bioelectrical signals recorded from maternal abdominal wall. Fetal electrocardiogram and uterine electrical signal are extracted from abdominal signals using advanced instrumentation and algorithms for signal processing. We expect that evaluation of fetal heart rate variability with additional analysis of fetal electrocardiogram morphology will ensure early detection of fetal hypoxia symptoms and finally an appropriate obstetrical intervention.

Introduction

Information on fetal heart rate and uterine contraction activity is a basis for biophysical monitoring of a fetus and mother during pregnancy and labour. So far it is accomplished by mechanical approach. Applying the Doppler principle of ultrasound waves aimed at the fetal heart enables monitoring of the mechanical activity of the fetal heart. Determination of instantaneous fetal heart rate (FHR) relies on the detection of heart beats based on the analysis of ultrasound beam reflected from the moving valves or walls. Uterine contraction activity (UC) is recorded with a help of tocodynamometric transducer attached to maternal abdomen, which measures a pressure exerted by uterus on abdominal wall [2]. FHR and UC signals together with fetal movement activity provide information for evaluation of fetal well-being. The undoubted advantage of Doppler ultrasound technique and external tocography is simplicity of application and non-invasiveness, but their accuracy is rather low. Accuracy of FHR determination provided by the ultrasound technique is sufficient only for visual interpretation. The automated analysis comprising evaluation of variability at a level of single heart beats requires a much higher accuracy [8]. Contractions rate provided by tocography is measured with accuracy comparable to direct measurement of intrauterine pressure, but the contraction duration - with a lower precision, and the amplitude value represents the strength of contraction only in approximate way. Due to limited accuracy and sensitivity the tocography is used mainly to control the labour progress.

At the same time, in the common opinion mechanical methods are very subjective and do not provide credible information on functioning of the organs being examined. These disadvantages result from the fact that as the indirect measuring techniques, they records the effects of electric excitation i.e. fetal heart movement and mechanical contractions of uterus. Considerably higher accuracy and reliability can be obtained by recording of the primary bioelectric signals: fetal electrocardiogram – FECG and electrohysterogram – EHG as an electrical activity of uterine muscle. Consecutive cardiac cycles can be determined more accurately basing on detection of QRS complexes in fetal electrocardiogram than on analysis of reflected ultrasound beam of a very complex shape. From the other hand, electrohysterography seems to be more sensitive than mechanical tocography. There is a common opinion that electrical approach can provide more comprehensive information for early recognition of disorder of central nervous system or for detection of premature labour.

Two techniques of fetal electrocardiogram registration can be distinguished: direct and indirect. The direct method consists in electrocardiogram recording by means of scalp electrode placed on fetal presenting part (ussually head). Invasiveness of the method and restriction of its use exclusively to labour period causes its rare application. Indirect fetal electrocardiography relies upon recording of electrocardiogram with the use of electrodes placed on abdominal wall of pregnant woman. Indirect method is completely noninvasive and can be used in practice from the 16th week of gestation. Similarly as fetal electorcardiography, the electrohysterography uses electrodes positioned on maternal abdominal wall but it records action potentials of myometrium cells. The problems with measurement and analysis of bioelectrical signals in the presence of usually strong interference – maternal electrocardiogram and muscular artefacts have made impossible the application of electrical approach as a widespread diagnostic method. Continuous technical progress and common accessibility of computer-aided signal processing caused the renewed increase of interest in indirect electrocardiography and electrohysterography.

The aim of this paper is to present some problems which were resolved during development of the system for fetal monitoring based on recording and analysis of electrical signals only.

Materials and Methods

We have developed a system for acquisition and analysis of bioelectric signals being recorded on maternal abdominal surface (Figure 1). The system generally consists of two separate parts: the microcontroler based recorder of bioelectric signals and external computer. Recording circuit in a form of external, optically isolated module enables both the FECG signal acquisition and electrical uterine activity by using the same signals being recorded from maternal abdomen. Typical configuration of the abdominal electrodes comprises four electrodes placed around the navel and the reference electrode placed above the pubic symphysis. Additionally on the left leg, the common mode reference electrode is placed. The necessity of using a few abdominal leads results from the fact that very often the FECG signal of a good quality occurs only in one lead, whereas in the others it is practically not observed. Electrical activity of uterus is presented in all leads, however the strongest differential signal is obtained in the channel which is formed by two electrodes placed in the vertical median axis of the abdomen.

Figure. 1. System for recording and analysis of bioelectric signals from maternal abdominal wall.

The basic merits of the developed recording module are very low level of its own noise which does not exceed 0.5 µV (peak-to-peak) measured with reference to input (RTI) and large value of CMRR coefficient (120 dB) that ensures the proper suppression of main interference. These parameters have been obtained thanks to novel recorder structure (Figure 2) including complete separation of analog part from a digital one [3].

In each of the four measuring channels, two preliminary amplifiers are used having constant gain equal to 20 and 25 V/V respectively that have been separated by the DC-component cut-off circuit. The next stage is formed by band-pass filters and end amplifiers with gain adjustable in the range of 1 to 255 V/V. Entire circuit allows the amplification of recorded signals from the tens of microvolts up to level of a few volts. Gain adjustment prevents the reaching of saturation state by the amplifiers in case of strong isoline drift. Moreover, the band-pass filters allow the change of lower cut-off frequency from 0.05 Hz to 1 Hz, thus also securing the circuit against too large low-frequency interferences. High cut-off frequency of filters is established at 150 Hz, hence at the sampling frequency of 500 Hz, the recorder circuit is fully protected against a possibility of aliasing occurrence.

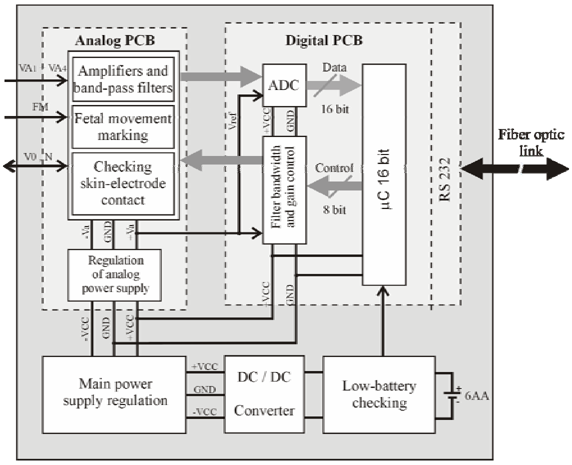
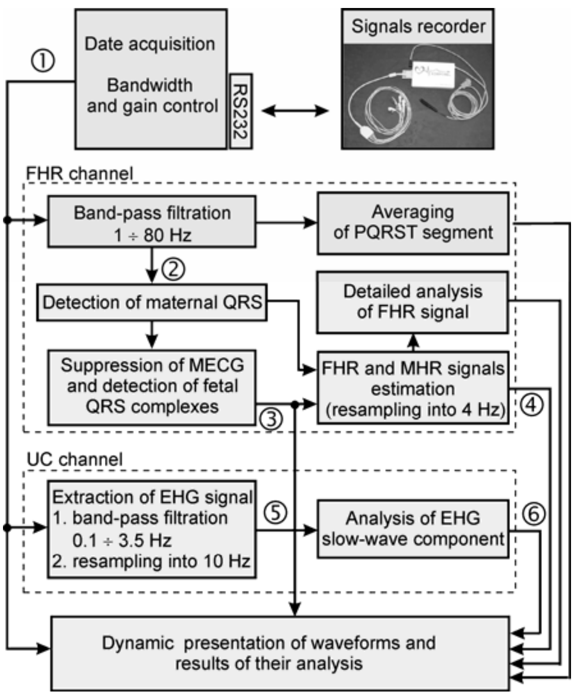


Figure. 2. Block diagram of bioelectric signal recorder.

Application of the fiber optic link between recording module and computer as well as battery supply of the module ensure full safety of a mother and her baby during measurement. The task of external computer is to store the incoming data, their on-line analysis and adequate graphical presentation on a monitor screen.



ISSN: 1727-1983 © 2005 IFMBE

Figure. 3. Structure of the program for acquisition and analysis of signals recorded from maternal abdomen.

The software of the system has been developed basing on LabView (National Instruments) graphical environment for building signal processing applications (Figure 3). The program enables the appropriate control of bioelectric signals recorder.

The aim of analysis is to ensure at least the same information as provided by mechanical approach: fetal heart rate and uterine activity signals. The signals obtained in the consecutive stages of analysis are presented in Figure 4.

The electrohysterogram has the frequency range between 0.1 and 3.5 Hz, and its amplitude can achieve 500 μV. This characteristics makes extraction of EHG from abdominal signal quite easy by the use of filtration technique. Electrical uterine activity component is separated from abdominal signal in selected lead, by means of band-pass filtration (Figure 3). The method of extraction of slow wave from EHG signal has been based on calculation of consecutive root-mean-square values in 60 sec window stepped with 3 sec [4, 5]. The basal tone is a reference for detection of uterine contractions and calculation of their timing parameters. Consecutive values of basal tone are determined in windows 4 min wide and stepped with 1 min. In every step, samples are ordered from the lowest to the highest value and the mean value from 10 % of samples from a lower side is calculated. The threshold value for contractions detection is obtained by adding to basal tone the value equal to 25 % of signal range in the analysed window. Contraction is detected when its duration is greater than 30 sec and its amplitude is higher then double value of the threshold.

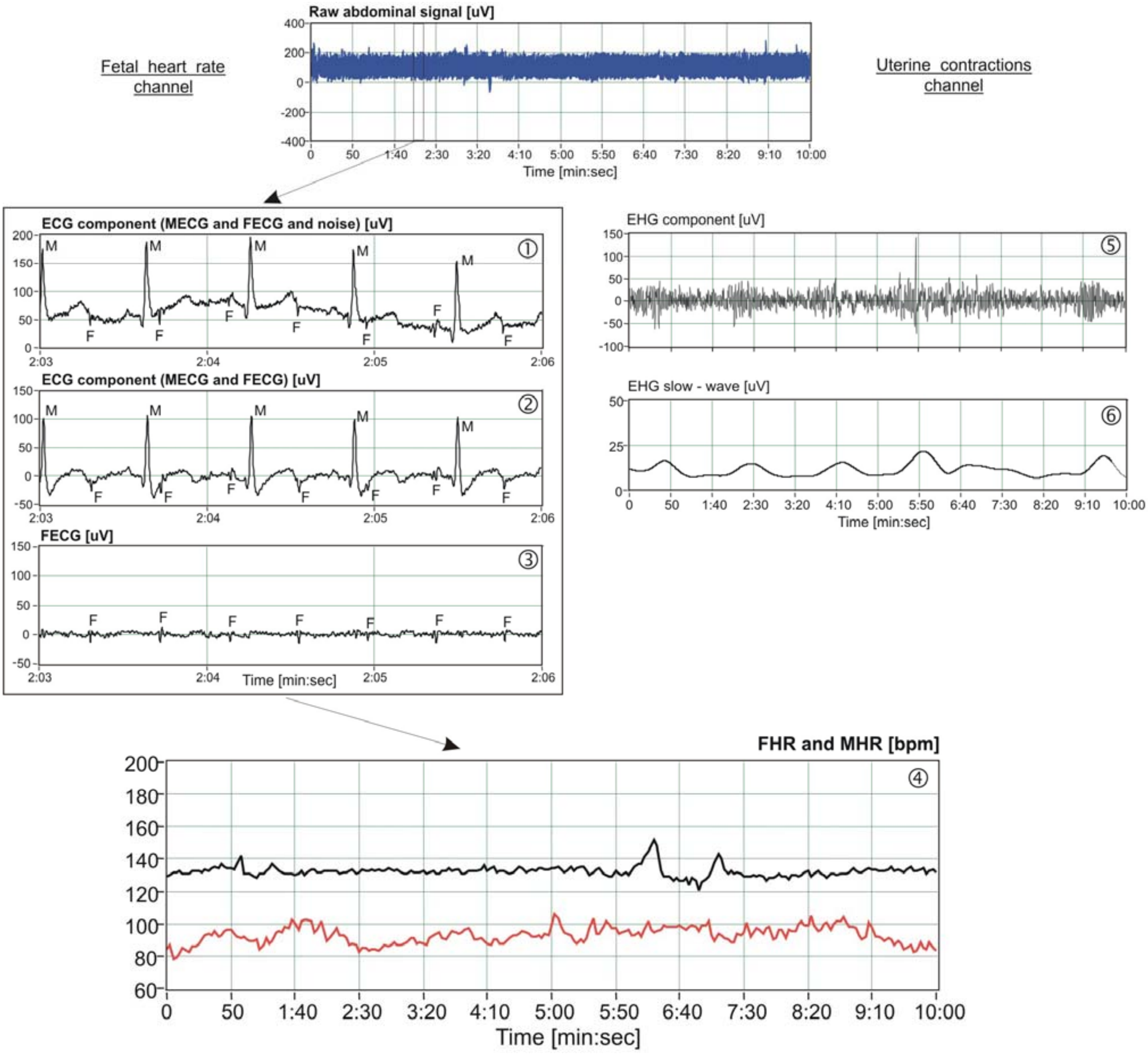


Figure. 4. Signals obtained in the successive stages of analysis of fetal heart rate and uterine activity. M – maternal, F – fetal QRS complex. Numbers on plots correspond to numbers on the program structure presented in Figure 3.

ISSN: 1727-1983

Analysis of FECG comprises the initial filtration of low-frequency interferences, suppression of interfering maternal electrocardiogram (during this process the signal of maternal heart rate is also determined), detection of the fetal QRS complexes and thus calculation of the FHR signal.

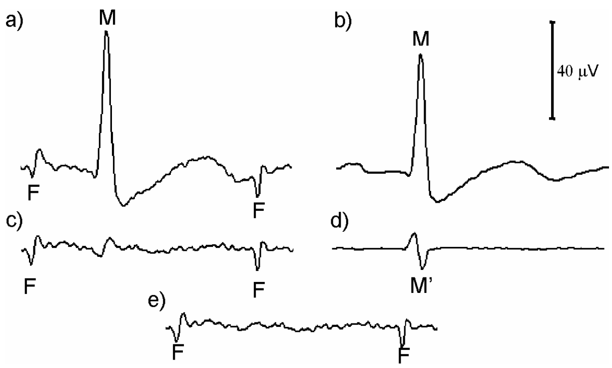


Figure. 5. Suppression of maternal electrocardiogram: a – fragment of analysed abdominal signal, b – PQRST pattern of MECG signal, c – FECG signal obtained only from subtraction of PQRST pattern, d – first derivative of maternal QRS complex, e – FECG signal obtained from subtraction of PQRST pattern and the first derivative of maternal QRS complex.

In case of fetal electrocardiogram analysis suppression of the dominating signal of maternal electrocardiogram is the first, and at the same time, the decisive step in whole analysis [1, 6]. Electrocardiogram of the mother (MECG) is a very strong interfering signal. Its amplitude of about 200 µV is much higher than fetal electrocardiogram amplitude, which reaches level of only 10 µV. Frequency range of maternal QRS complex covers the range from 10 to 40 Hz, whereas the fetal QRS complex starts from 20 Hz. When analyzing power density spectrum of abdominal signal we have noted that in whole common range maternal QRS is still a dominant component. Such signal characteristics of fetal and maternal electrocardiograms make the suppression of MECG by the simple filtration impossible, because it would lead to full suppression of FECG as well.

The method of MECG suppression that has proposed by us is a result of our previous research work [7]. It is based on precise subtraction of averaged maternal QRS complex in each abdominal channel. Reference QRS complexes of maternal electrocardiogram are created and then after scaling they are subtracted from successive maternal QRS complexes in each abdominal signal. The phenomenon of inaccurate pattern synchronization can be eliminated by subtraction of the first derivative of maternal QRS complex pattern. This leads to full suppression of MECG and does not influence FECG component (Figure 5). The detection and the exact location of the consecutive QRS complexes in FECG have the main influence on determination of the FHR. The decision making algorithm is used to detect the peaks of the detection function which are responses to the occurrences of the QRS complexes.

Results

The developed system performs the classical analysis of FHR variability which comprises detection of accelerations and decelerations patterns, recognition of bradycardia and tachycardia, interpretation of short- and longterm FHR variability. Using contractions curve, the contractions detection and calculation of their basic descriptive parameters: starting time, duration, amplitude and area are performed in a similar way as in case of conventional tocogram, which is shown in Figure 6.

Figure. 6. System window with traces and graphically presented results of their analysis: detected FHR accelerations patterns, contractions recognized in UC signal.

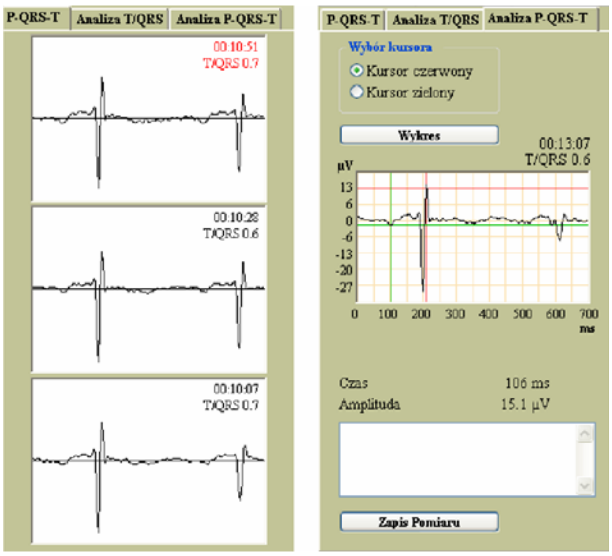


Figure. 7. Fetal P-QRS-T morphology analysis. On the left side there is a window showing three recently averaged fetal P-QRS-T complexes together with values of T/QRS coeeficient automatically determined. On the right side there is a panel used for manual measurment

of additional amplitude-time relationships in the averaged P-QRS-T complex.

Measurement of electrical activity of fetal heart enables to carry out assessment of the morphology of the fetal QRS complexes, comprising measurement of an amplitude and time dependences between individual waves, mainly analysis of the ST segment, determination of the ratio of T wave amplitude to the QRS complex amplitude (see Figure 7).

Conclusions

The electrical approach to monitoring of fetus and mother during pregnancy and labour has been implemented in computer-aided system. The presented system offers the same or even higher functionality than a standard fetal monitor which operation is based on mechanical approach. The measurement of fetal heart rate, maternal heart rate and uterine activity signals and their standard automated analysis are ensured. The electrical approach enables not only standard analysis of acquired signals in time domain but also in frequency domains, which will be the next step of our research work in this area. In addition, analysis of FECG signal morphology and electrophysiological properties of uterus can be carried out. This kind of analysis seems to improve the efficiency of fetal distress diagnosis. The described system allows replacement of the expensive cardiotocographic instrumentation and ensures the higher diagnostic capacity at the same time.

Acknowledgment

Scientific work financed from the State Committee for Scientific Research resources in 2004-2006 years as a research project No. 3 T11E 017 26.

The second author is fellowship holder of the Foundation for Polish Science.

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