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MONITORING OF FETAL MOVEMENTS BASED ON ACTOGRAM SIGNAL ANALYSIS

At present, biophysical fetal monitoring relies mainly on evaluation of a fetal heart rate (FHR). Absence of the FHR variability indicates central nervous system depression associated with hypoxia. The analysis of fetal heart rate segments identified with the aid of information on fetal movement activity provides much better results than analysis of the whole signal. Automatic recording of the fetal movement activity in a form of actogram signal provided by new models of fetal monitors becomes very common. For evaluation of information content of the actogram signal, the measurement instrumentation has been developed. The examined group comprised 20 patients and the total time of recording was 10 hours. Correlation between movements observed by clinical experts on ultrasonographic image and actogram trace recorded by fetal monitor was analysed. Although for head, arms, legs and trunk movements just visual analysis let observe their correlation with actogram signal, but in case of breathing movement no correlation was noted. Depending on movement type the detection efficiency was in range from 54 % to 80 %.

1. INTRODUCTION

Cardio-tocography is a basic method of fetal well–being assessment. These results from the fact that correct fetal heart rate demonstrate a good supply of blood and proper functioning of central nervous system. Cardio-tocographic monitoring relies on simultaneous recording of fetal heart rate (FHR) and uterine contraction activity [3]. Among many different techniques of recording of FHR signal, the most popular is indirect Doppler method. Contrary to direct electrocardiography from a fetal scalp, this method is non–invasive and in addition allows fetal monitoring also during pregnancy. Determination of intervals between consecutive cardiac cycles, and thus an instantaneous fetal heart rate, relies on detection of the fetal heart systoles and diastoles using Doppler shift of ultrasound beam reflected from moving valves or walls of fetal heart [4]. Complexity and variability of Doppler signal make difficult the precise measurement of consecutive intervals [2]. Therefore advanced algorithms based on correlation techniques are used for estimation of FHR signal [1].

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Generally ultrasound beam of the frequency from 1 to 2 MHz is used. Such ultrasound wave penetrates mother's abdomen deeply enough in order to encompass the fetus. Measurement based on echo reflected from valves is more accurate because of shorter duration time of pulse and more evident maximum related to velocity changes [5]. However focusing of beam on valves is difficult particularly in low weeks of gestation. Therefore Doppler signals corresponding to valves and wall movements are compared, and stronger is chosen [9]. If beam encompasses both wall and valve then echo from valve is automatically chosen. Extraction of walls and valves signal components from complete echo signal is carried out in frequency domain. Components of lower frequencies (150÷250 Hz) correspond to fetal heart walls movement whereas higher frequencies (250÷600 Hz) components correspond to valves movement.

Prelabour cardio-tocography is based on application of so called non-stress test. For correct evaluation of test information on fetal movement activity is very important. It lets evaluate reliability of true non-reactive tests, which means cases where fetal movements' activity is not accompanied by accelerations episodes in FHR signal. Additionally information on movement activity allows segmentation of FHR traces, and then their separate analysis. Prediction value of segments identified on a basis of fetal movement activity – most often breathing movements, is much higher [6,8]. Statistically significant increase of instantaneous FHR variability at the time of duration of breathing movements in physiological pregnancy has been noted. Additionally, in case of pregnancy complicated by fetal hypotrophia a maximum of FHR power density function corresponding to breathing movements has much higher amplitude in comparison to physiological pregnancy.

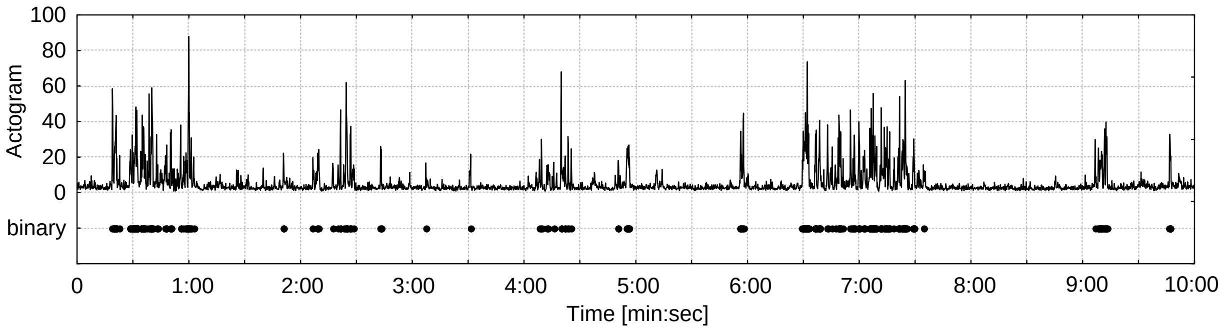

Fig. 1. Automatically recorded a fragment of fetal movement activity signal (actogram) presented in continuous and binary forms.

In physiological pregnancy the periods without fetal movements should not last longer than 60 to 75 minutes. Movement activity increases when pregnant mother is put on her left side, between 9 p.m. and 1 a.m., as well as when a level of glucose in maternal blood increases. The first source of information on fetal movements applied in cardio-tocography was markers of movements perceived by mother. However, such technique is very subjective and depends on many factors, such: gestational age or fetal growth. Various experiments showed that mother perceives only 20 % of fetal movements. The rest 80 % can be monitored only with a help of dedicated medical equipment. The most accurate method, allowing determination of type and intensity of movement is ultrasonographic imaging. In 1980 was initiated standardization of ultrasonographic examination on a basis of so called biophysical fetal profile, whose aim is determination if autonomous nervous system functions correctly. In this profile five parameters are tested – three of them concern movement activity. Presence of trunk and limbs movements, stretches and breathing movements are detected. In addition, presence of fetal heart rate acceleration as reaction on fetal movements are analysed and capacity of amniotic fluid is evaluated. Minimal observation time of a given parameter, necessary to judge it as incorrect, should be at least 30 minutes. However, for 4 % of population quiet sleep (1F behavioral state) can be longer and therefore observation time must be increased. Unfortunately, such kind of examination has limited accessibility because it requires high cost equipment and takes medical staff a lot of time.

Analysis of actogram being integral part of cardio-tocogram becames a method that is the most often used for evaluation of fetal movement activity. Actogram signal, just as FHR is obtained using Doppler ultrasound method. Fetal movements have instantaneous velocity lower than valves and walls. Depending on type of the movement its velocity varies from 1 to 3 cm/s. For ultrasound transducer operating with frequency of 2 MHz this range corresponds to Doppler frequency range equal to 20÷80 Hz [7]. Extending of frequency range enables detection of other movements e.g. coming from eyes, but at the same time it increases sensitivity to interferences caused by reallocation of transducers or maternal movements. There are two representation of actogram. In the first actogram is expressed in a form of set of values normalized into a range of 0÷100 units representing instantaneous intensity of fetal movement. It is called continuous actogram which is presented in a form of spike plot on recorder paper. The second representation is a binary actogram depicting only the fact of movement appearance (movement noted or not), without any information about its instantaneous intensity (Fig.1). Binary actogram is a result of comparison of established discriminative threshold with continuous actogram curve. When the curve exceeds the threshold level a movement is detected and graphical marker is printed on a paper.

The aim of this work was evaluation of actogram signal as a basic source of information on fetal movement activity.

2. METHODOLOGY

Accomplishing of established aim required a development of measuring station, whose integral part was fetal monitor equipped with module for recording of fetal movement activity (Fig.2). The MT-430 fetal monitor (TOITU, Japan) was used in our study, it is designed to monitor twin pregnancy, therefore it comprises two non–interfering measuring channels.

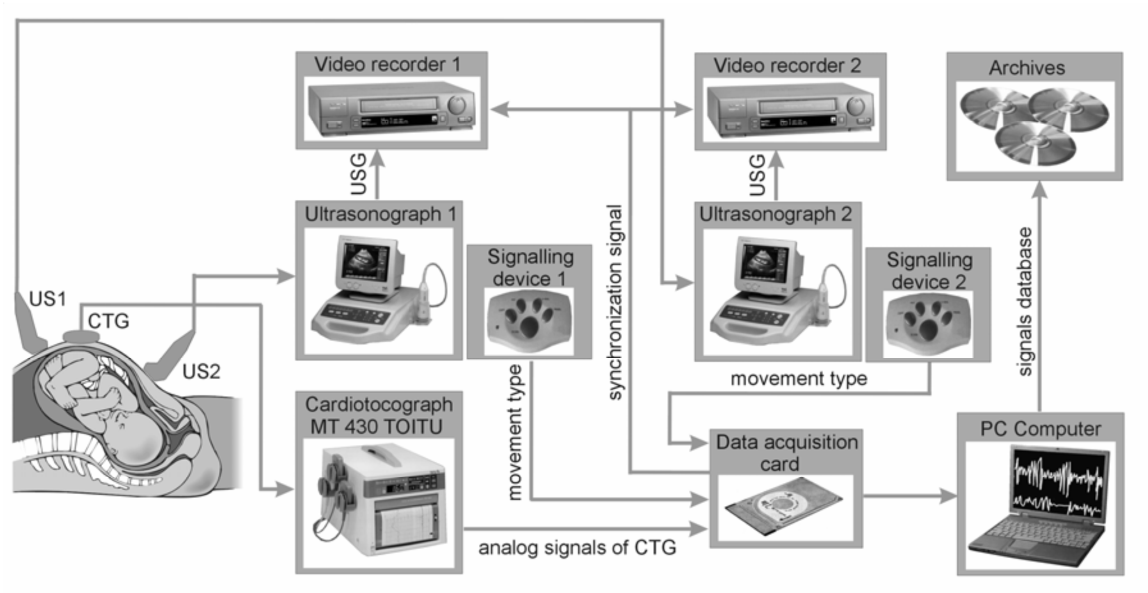

Fig. 2. Block structure of monitoring instrumentation for simultaneous acquisition of biophysical signals and ultrasonographic images.

Phase shift between transmitted and received signals applied in particular channels ensures a lack of disturbances. Both channels were used during study that allowed continuous recording of selected signals even in a case when signal loss occurred in one of the channels. Fetal heart and fetal movement activity signals being objects of our study are accessible both from digital and analog output of described fetal monitor. In our study, only analog output signal were used because accuracy of digital output signals were unsatisfying. Accuracy of 1 bpm of digital FHR signal representation is not enough for the determination of instantaneous FHR variability. Established standard in cardio-tocography is the accuracy of 0.25 bpm.

In order to ensure reliable source of reference providing complete information on movement a parallel ultrasonographic imaging of movement activity has been used. Selection of ultrasonograph type was not accidental, because it had to ensure lack of disturbances caused by interference of signals emitted by ultrasonograph and fetal monitor ultrasound transducers. On a basis of series of experiments we stated that device with a sector ultrasound transducer could not be applied. Disturbances occurring in that case resulted from specific principle of operation of such transducer. Synchronously with switching frequency of beam into consecutive lines of transmitting–receiving elements matrix, disturbances occurred in echo signal, which made impossible correctly functioning of monitor. Determined FHR and movement activity signals were characterized by significant error and therefore their further analysis had no sense. Requirement concerning lack of disturbances was ensured by ultrasonograph equipped with a linear transducer.

Two identical ultrasonographs were used in our study, the first for imaging of upper, and the second for the lower part of fetal body. In the area of upper part of body movements of head, upper limbs and diaphragm were observed, whereas lower part provided information on trunk and lower limbs movements. Observation of diaphragm gave information on occurrence of breathing movements. Results of ultrasonographic image analysis in a form of markers (movement was observed or not) were stored into computer hard disc. Signaling device was developed to point movement type. In our study two such devices were used, whose keyboards handled movements visible on a selected ultrasonograph. Signalling devices were equipped with extra switch for signalling of poor quality of signal, when strong disturbances occurred that was caused by reallocation of ultrasonographic transducer and movement of patient. Signalling devices were powered from computer, and their outputs with cardio-tocographic signals were led to analog inputs of data acquisition card DAQ 6062E (National Instruments) cooperating with notebook computer. The signals were sampled with frequency of 16 Hz and resolution of 16 bits and written to file. Thanks to battery supply, complete safety for patient was ensured without using electrical barrier between computer and fetal monitor.

Since results of longitudinal analysis of ultransonographic image seem to be subjective, which is consequence of tiredness of person analyzing the trace, possibility of work in additional retrospective mode has been introduced. For retrospective analysis the recording of ultrasonographic image on videotape was necessary. We used two video recorders connecting to two ultrasonographs. We developed method which ensured full synchronization between signals acquired via DAQ card and images recorded on videotape. Frequency coded state of second counter was put every second into audio channel of video recorder. Coded signal was generated with a help of generator built–in acquisition board.

Assuming that trace length does not exceed 60 minutes, its duration in seconds can be represented with a help of 12 bits (4096). High state – “1” corresponds to the frequency of 100 Hz, whereas low state – “0” to frequency of 200 Hz. For separation of bits and determination of start and end of binary representation of current time value in set of bits the idle state was added, which frequency was equal to 500 Hz. The value of trace duration was written into file containing data from fetal monitor and signalling device. This made possible reanalysis of ultrasound image reproduced from video recorder. At the time of retrospective analysis utrasonographic image was obtained from video output, whereas synchronization signal from audio output. Occurrence of a given movement was marked with a help of signalling device on a basis of image analysis performed by clinical expert. Data from signalling device together with synchronization signal were led to acquisition card and written into file. Recorded in such way data created information database used to verify on–line records. System software was developed in LabView environment. During recording it was possible to monitor all measured signals, which let evaluate correctness of working instrumentation at once.

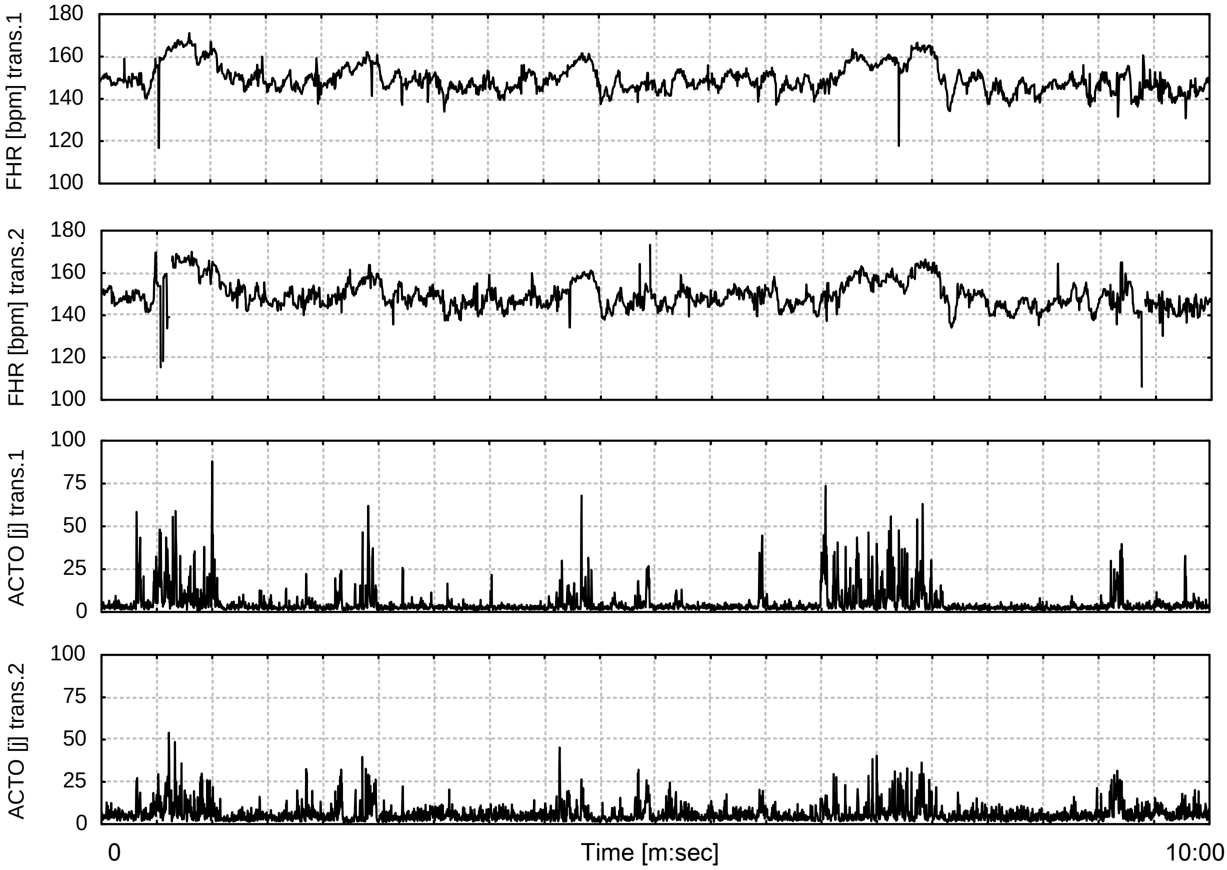

Fig. 3. Cardiotocographic signals recorded during monitoring session: FHR and ACTO via two separated ultrasound transducers.

Examination was carried out on the following way. At first, fetal monitor transducers were localized on those places of maternal abdomen which ensured the best quality of signal. Then, two clinical experts placed ultrasonographic transducers on maternal abdomen, so as to obtain the best possible imaging of upper and lower part of fetal body. On a basis of image analysis experts informed technical staff about occurrence of a given type of movement and then technician using signaling device set relevant markers. That let acquire information on fetal head, limbs, trunk and breathing movements. Every performed examination was verified by retrospective analysis which ensured high reliability of obtained results.

For successful monitoring appropriate localisation of fetal monitor transducers is very important. Influence of transducers localization on quality of recorded CTG signals shows Fig.3. Both FHR and ACTO signal from transducer 1 have better quality than analogical signals from transducer 2. In FHR signal lower signal–loss level can be noted, whereas ACTO signal has higher amplitude in places of movements’ occurrences and lower outside of them.

Method of movement activity analysis requires conversion of continuous actogram into binary one determining only the fact of movement occurrence. Binary actogram is a result of comparison of threshold level with continuous actogram curve. In these moments where curve exceeds established level a movement is marked. Figure 4 presents example of continuous actogram along with binary signals determined for various values of threshold level. Additionally, signals describing occurrences of particular types of movements obtained on a basis of ultrasonographic image analysis are showed. Definition of complex movement has been also established – complex movement comprises simultaneously occurrence at least two types of movement excluding breathing movements.

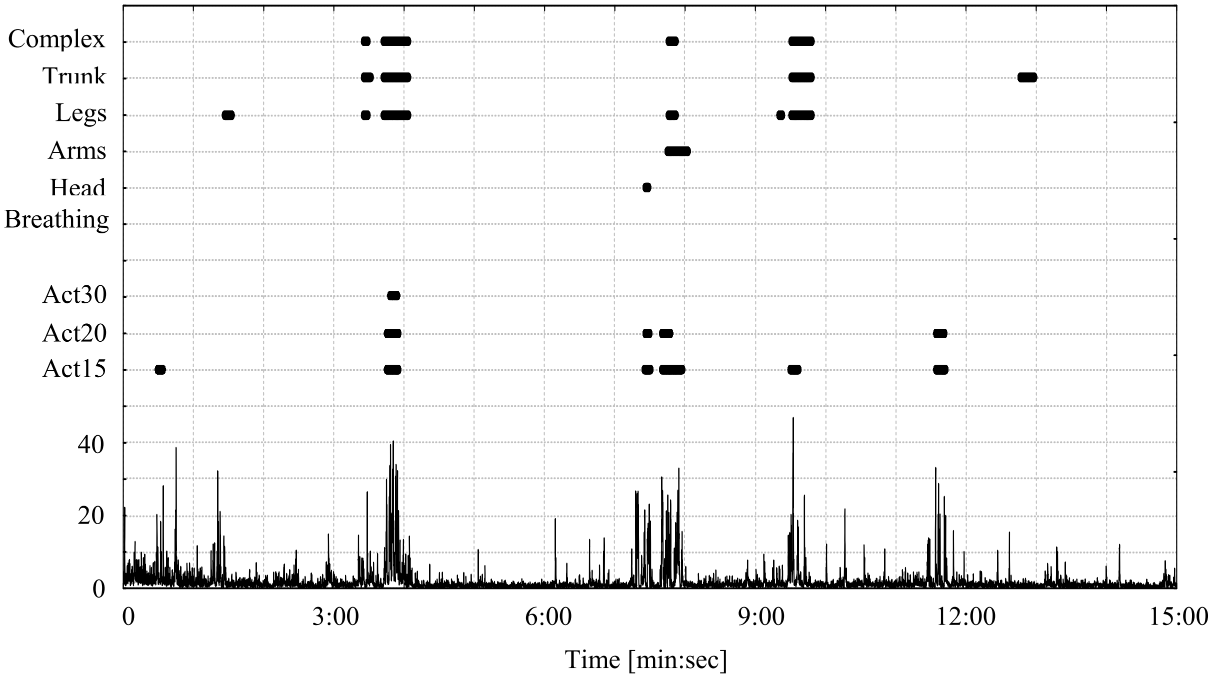

Fig. 4. Example of continuous actogram together with the determined binary signals and movement markers obtained from pararell ultrasonographic imaging.

3. RESULTS

Collected database contains twenty multi-channel records of various duration recorded between 26th and 40th week of gestation. Mean duration was 32 minutes, which corresponds to typical cardio-tocographic monitoring. Using collected database correlation between movements marked by experts from ultrasonographic image and actogram trace recorded by fetal monitor was analysed.

In case of proper localization of cardio-tocographic transducer interfering noise in actogram does not exceed value of 10 units. Despite short–lasting artifacts caused by maternal movements the actogram values exceeding 10 units were related to fetal movement activity, with maximum values about 50 units. Although for head, arms, legs and trunk movements, just visual analysis let observe their correlation with actogram signal, that in case of breathing movement no correlation was noted. Characteristic of breathing movements (relatively low amplitude and velocity) makes them invisible on a background of interfering noise. Additionally we noted that duration of movements noticed during ultrasonographic examination is usually longer, than its equivalent in actogram signal. It can be related to velocity change of moving of a given fetal body part. Fast movement phase is reflected in a form of high values of actogram, whereas decreases of movement velocity occurring in its end phase have much lower amplitude, often of a noise level.

There were cases noted in some records, where movement found in actogram had not its equivalent in ultrasonographic examination. Indeed, those were short–lasting artifacts caused by maternal movements. Interfering artifacts were eliminated by assuming minimal duration of movement. If duration of an episode in actogram signal did not exceed two seconds then this episode was regarded as artifact and it was not analysed.

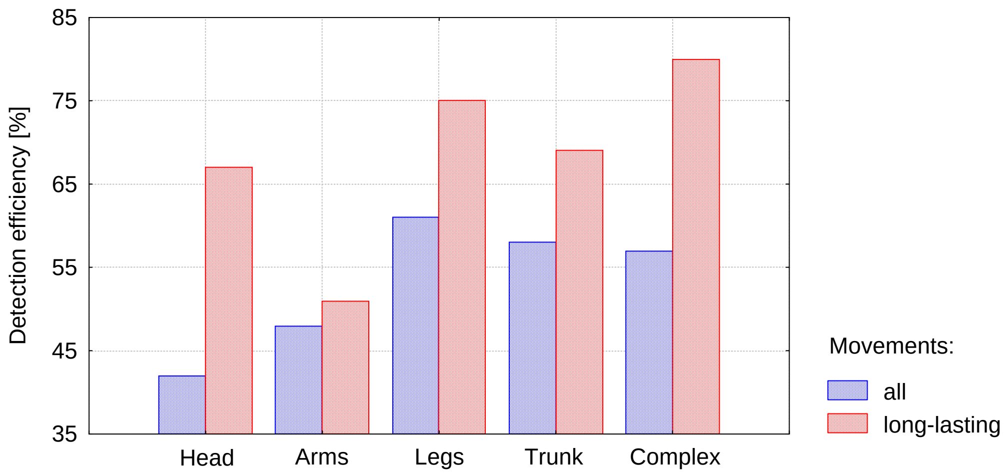

Fig. 5. Detection efficiency of particular types of movements for the collected database (20 records)

Using collected database maximal correlation between movement detected by actogram and observed in ultrasonographic image were reached for the threshold level equal to 15 units. Figure 5 shows results determining efficiency of detection of particular type of movements. The lowest efficiency was noted for head and arms whereas trunk, legs and complex movements were recognized with higher (of more then ten percents) efficiency. Detection efficiency was significantly higher for long–lasting movements – of duration time exceeding 15 seconds. Generally, detection efficiency of isolated movements, which means occurring independently, was 54 %, however for long–lasting efficiency was 70 %. Better results were obtained in a case of complex movements – 57 %. Long–lasting movements were recognized with efficiency of 80 %. According to results published elsewhere mother perceives only 20 % of fetal movements. Relating this to our results we can state that actogram signal is a very powerful tool for fetal movements detection.

4. DISCUSSION

Monitoring of fetal movement activity with a use of fetal monitor with actogram, makes possible detection of most events occurring at the time of cardio-tocographic monitoring. Such information lets increase positive prognostic value of non–stress test, and additionally improves diagnostic efficiency of FHR analysis. Performing analysis of actogram, a presence of artifacts that only suggest movement has to be taken into account. Interfering artifacts can be partially suppressed by establishing of time criterion determining minimal duration of the movement.

There was not correlation noted in our records between actogram and breathing movements observed in ultrasonographic image. This relates to relatively low amplitude and velocity of this type of movement which makes them invisible on the background of interfering noise. However, information on fetal breathing activity can be obtained using joint time–frequency analysis of FHR signal. In this type of analysis a proper preparation of data is very important to emphasize events interesting from metrological point of view. Procedure of automated breathing movements detection on a basis of FHR spectrogram is now one of our main research topics.

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