DEVELOPMENT OF THE SOFTWARE ANALYSIS SYSTEM FOR ULTRASONIC DOPPLER SIGNALS OF FETAL MOTOR ACTIVITY

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Abstract: Fetal motor activity is an important indicator of fetal well-being. It would be of interest to elaborate an objective and automatic fetal activity assessment method suitable for long time fetal monitoring and presenting no special burden for the medical staff. Such system, making use of ultrasonic CW Doppler information resulting from various fetal movements, is being developed. Its enables the acquisition and analysis of Doppler signals of fetal activity using a standard PC equipped with sound card. Displacements of the structures, velocities and accelerations of the displacements are computed. Fetal cardiac rhythm is also determined. Two methods of displacements and velocities calculation are implemented. One uses analysis of phase of the analytical Doppler signal, the other is based on mean frequency estimation from the short-term signal spectrum. Velocities and accelerations of the movements are calculated and presented as histograms. Parameters of the histograms (median, kurtosis, standard deviation, skewness) are computed and create the features vector, which describes fetal activity during examination. The software system was tested on simulated signals and clinical data.

Introduction

The fetal activity observed as trunk movements, pseudobreathing movements or limb movements is an important indicator of fetal condition, especially the pseudobreathing movements allow to asses fetal well-being [10]. Fetal activity monitoring starts with maternal counting and ends up with multiple technical means for the detection of these movements [2,3]. The technique dominating nowadays is the echography [12]. The Doppler ultrasound also plays an important role in the detection of fetal movements [2,4,5,6,15]. The most widely used tool for the assessment of fetal well-being is cardiotocography – tracing the fetal heart rate and uterine activity [12]. Due to the large number of the false positive diagnoses resulting from this technique, the fetal biophysical profile was proposed as a means for fetal state evaluation [10]. The profile comprises the information on the presence of fetal body movements, pseudo-breathing movements, on the fetal tone and the amount of the amniotic fluid. The profile is collected using ultrasonography, which may last up to 40 min. This method of fetal state evaluation requires a qualified human observer, prone to subjectivity and is time-consuming. It would be of interest to elaborate an objective fetal state assessment method. A system for quantitative evaluation of the fetal motor activity, using the Doppler ultrasonic data, was created. It consists of a 2MHz continuous wave Doppler fetal motor activity detector, laptop equipped with sound card and specialized software for fetal movement analysis [1,8,9]. The Doppler fetal movement detector and laptop use battery supply to provide the requested patient safety. Current state of development of the software system is presented below.

Methods

The software system created in the LabVIEW® environment acquires the quadrature signals using sound card input and analyses Doppler signals ”on-line”. The software detects fetal movements, extracts features of these movements (displacements, velocities accelerations) and provides estimate of the fetal heart rate (FHR) as supplementary information [8].

Online acquisition and signal processing determined program organization. The assumption was made that any data loss must be avoided independent of the computer throughput. The program consists of three independent threads. First – the DSP - deals with the signal processing, second – the DAQ - with data acquisition, the third one, GUI, is responsible for communication with user and displays the results. GUI task starts and stops other tasks and also calculates digital filter coefficients. DAQ has the highest priority. This task receives samples as 16 bit signed integers from the sound card A/D converter and stores them in local memory buffer. It acquires data at 8kHz rate and decimates it down to 800Hz. The data from buffer is sent to the DSP thread when the previous portion of data was analyzed, and to the GUI task when previous part of information was presented. The Doppler data is processed in the DSP task [7].

Individual fetal motor activities can be detected in different frequency bands of the ultrasonic Doppler signals [5]. Assuming 2MHz emission frequency the spectrum of the pseudobreathing movements signals lays below approximately 60Hz, body movements can

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be observed in the range up to approximately 100-120Hz. The input quadrature signals are split into two bands by digital filtering (FIR). The signal in the first band (lowpass 60Hz filtering) is processed to detect pseudobreathing movements and to determine the rhythm of these movements, the second signal (heart structures movement band 60-150Hz) is used to determine the cardiac rhythm (Fig.1).

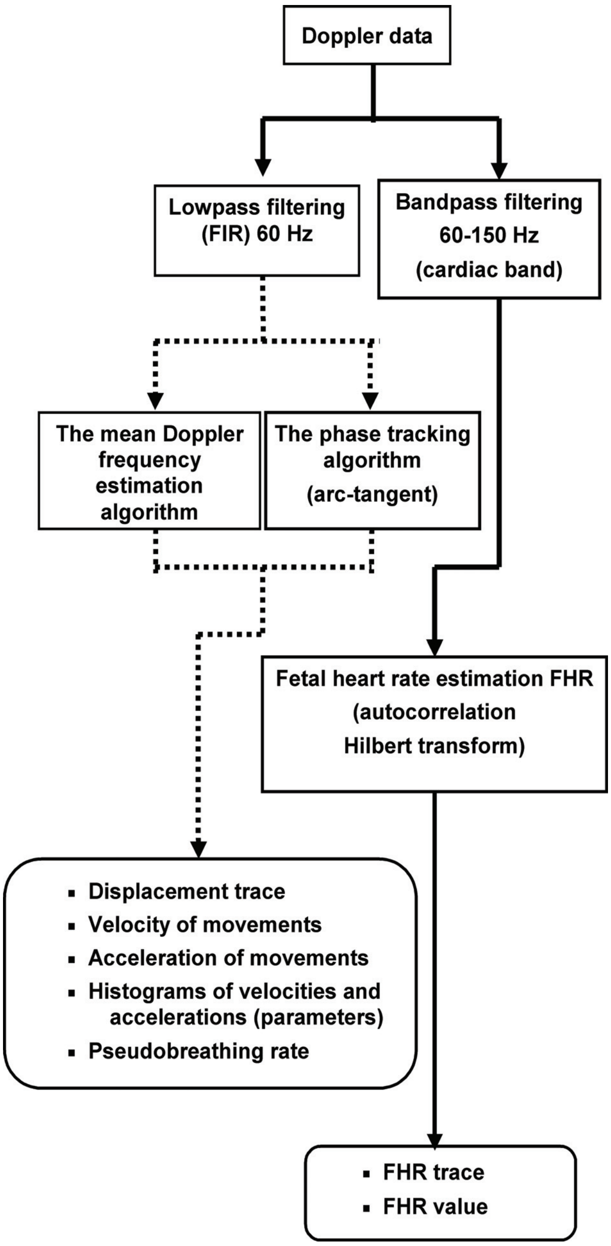

Figure 1: Doppler signals processing diagram

In the first version of the software displacements were calculated using signal phase tracking algorithm according to the formula:

$$\xi_r(t) = \frac{c_0}{2\omega_o}\left\{\arctan\left[\frac{Q(t)}{I\ (t)}\right] \pm k\pi\right\} \tag{1}$$

where: c_0 – sound velocity in the tissue, ω_0 - angular frequency of the ultrasound wave, Q(t), I(t) - samples of the output signals from the quadrature detector, $k\pi$ - correction due to arc-tangent function properties. The displacement is only computed when the mean instantaneous power of the signal in 50 samples long window exceeds a threshold. The threshold was experimentally estimated. The band of the movement signal is limited to few hertz. To reduce amount of data and decrease filters orders the displacement signal is decimated 50 times. The velocities and accelerations are obtained as suitable derivatives of the displacement trace [7].

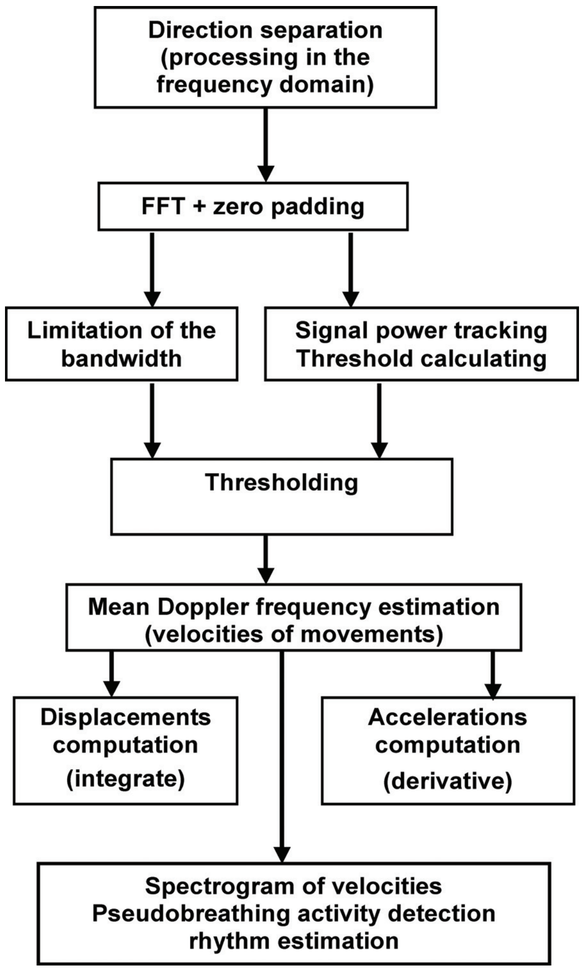

Figure 2: The mean instantaneous Doppler frequency estimation algorithm diagram

The clinical tests proved that the phase tracking algorithm suffers from low noise immunity [8,9]. Displacement determination based on noisy Doppler signals resulted in errors accumulating as drift of the displacement trace [8]. Therefore, an algorithm based on the mean instantaneous Doppler frequency estimation was proposed and implemented as an alternative movement detection method.

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Spectra of the signals due to movements in opposite directions are shifted to the opposite sides of the pilot angular frequency ω_p using the formula:

$$D(t) = I(t)\sin\omega_p t + Q(t)\cos\omega_p t \quad (2)$$

The D(t) signal is submitted to short-term Fourier spectrum analysis using 64 samples and zero padding up to 512 to increase the frequency resolution. Spectrum range is then limited around the pilot frequency to fit the frequency band of the interest signal (pseudobreathing movement band). Then the mean Doppler frequency of these spectra is computed and scaled to velocity units. The displacement curve is obtained by integration of this velocity signal and the acceleration is computed as smoothed derivative of the velocity (Fig.2.)

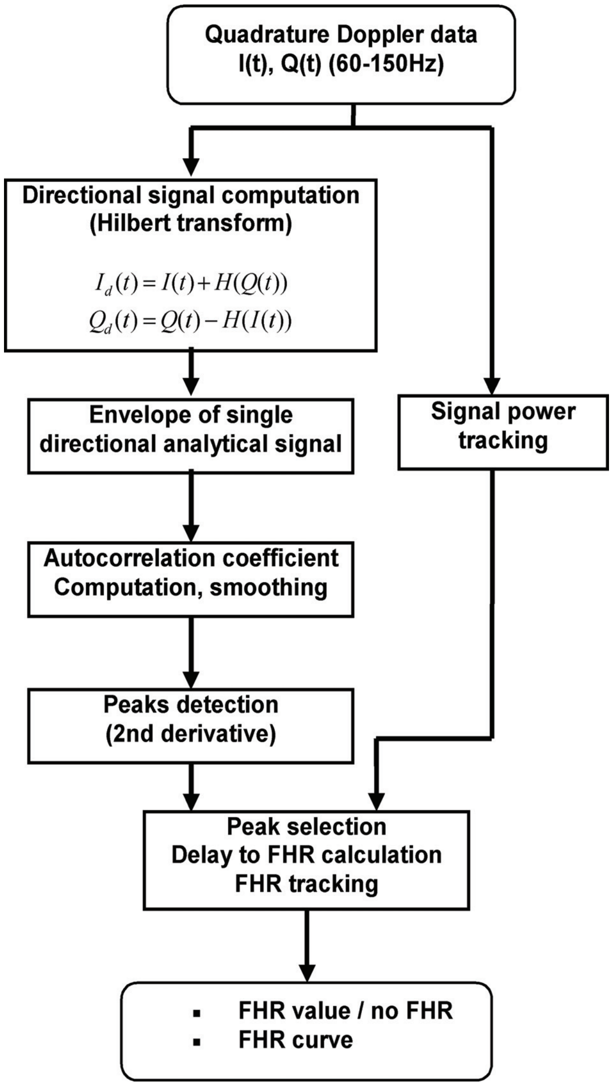


Figure 3: Fetal heart rate (FHR) calculation diagram

The presence of the breathing movements is detected on the basis of the spectral analysis of the movement velocity data (window size 64 points – approx. 5 sec). Maximum of the spectra observed between 0.5-1.5Hz indicates the presence of the fetal pseudobreathing activity period (Figs.7,6). The velocities and accelerations of movements are presented also as histograms (Fig.8). The parameters of histograms are computed – median, standard deviation, skewness and kurtosis. The histograms are continuously updated. The parameters of histograms and the result of the pseudobreathing movements detection will be passed to the classification system as a feature vector, describing the activity of the fetus (Tab.1).

The cardiac rhythm is determined from the single direction analytical Doppler signal. The quadrature directional components $I_d(t)$ and $Q_d(t)$ are calculated using following formulas:

$$I_d(t) = I(t) + H(Q(t)) \quad (3)$$

$$Q_d(t) = Q(t) - H(I(t)) \quad (4)$$

where I(t) and Q(t): quadrature components of the signal filtered in cardiac band, H(Q(t)) and H(I(t)): Hilbert transforms of the I(t) and Q(t).

The FHR is calculated using autocorrelation coefficient of the 1,5 sec. intervals of the Doppler signal envelope. The autocorrelation coefficient is only computed for the delay range 0.33-0.78 sec. (FHR range 77-180 bpm). The dominating autocorrelation peak corresponding to the current FHR value is automatically detected and tracked (Fig.3). Calculated FHR value is verified against FHR history. Only 10 bpm/sec FHR change is allowed [11]. If calculated value exceeds this limit or if the signal power in cardiac band is too low – information is provided that the system was not able to compute FHR value. If the result of subsequent computation is verified positively, the missed value is interpolated, otherwise the FHR trace is discontinuous.

Material

The developed software system was tested using simulated and clinical data [7,9]. The clinical data was acquired in the 2nd Department of Obstetrics and Gynaecology, Medical University of Warsaw. The protocol was accepted by the Human Investigation Committee.

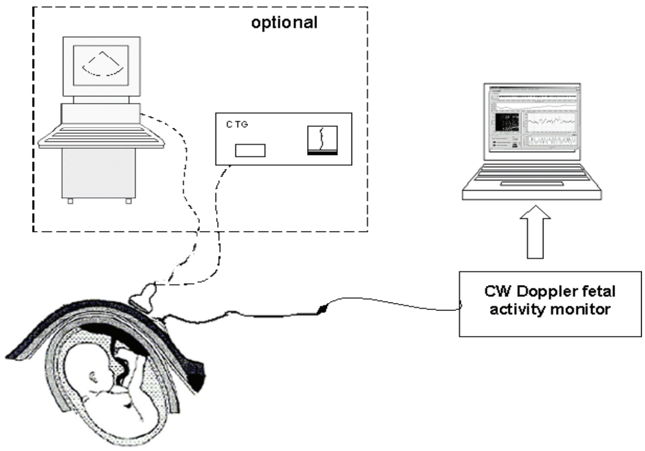


Figure 4: Diagram of the examination setup

Over 30 pregnant women were examined. The probe of the monitor was placed on the maternal abdomen, pointing towards fetal heart and diaphragm, localized using a cardiotocograph just prior to the positioning of the transducer. The Doppler signals from the monitor were fed to the sound input of the laptop and analyzed (Fig. 4). In a number of cases these signals were recorded on the audio track of the VCR with a concurrent video recording of ultrasonographic images. Such video recordings served the reference and facilitated the verification of the results of the Doppler signal processing [8].

Results

The main program window presents raw Doppler data, displacement trace, last FHR value and FHR trace, and spectrogram of velocities (Fig.5). The monitoring results over last hour are easily accessible using the chart sliders. All examination results are archived in files.

The Figure 6 shows results of processing of the same clinical recording. Sown are the results obtained using phase tracking algorithm (Fig.6a) and the mean Doppler frequency estimation algorithm (Fig.6b). The phase tracking algorithm result shows more tiny details, possibly due to interferences, whereas the mean frequency algorithm result shows sharply periodic pseudobreathing events. The pseudobreathing activity is also visible on the displacement trace and on the spectrogram of velocities (Fig.7).

The ultrasonographic (USG) validation of results was done off-line by comparing the 10 seconds lasting displacements patterns with the corresponding M-mode images. The M-mode USG scan shows approx. 1Hz oscillations of the fetal chest structures (Fig.9a) and the same oscillations are visible on displacement trace (Fig.9b). Some displacement drift resulting from the method properties can be seen (Fig.9b).

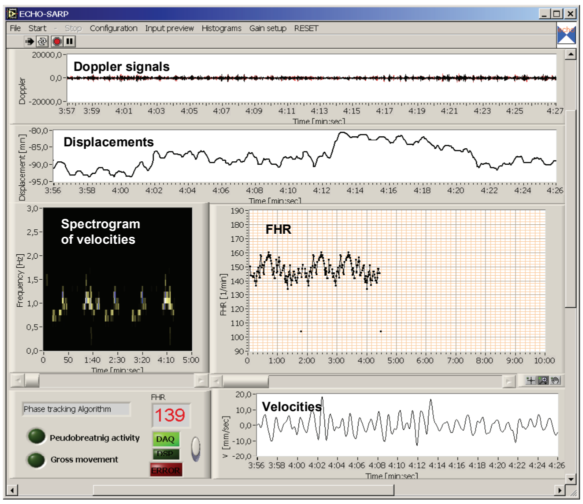
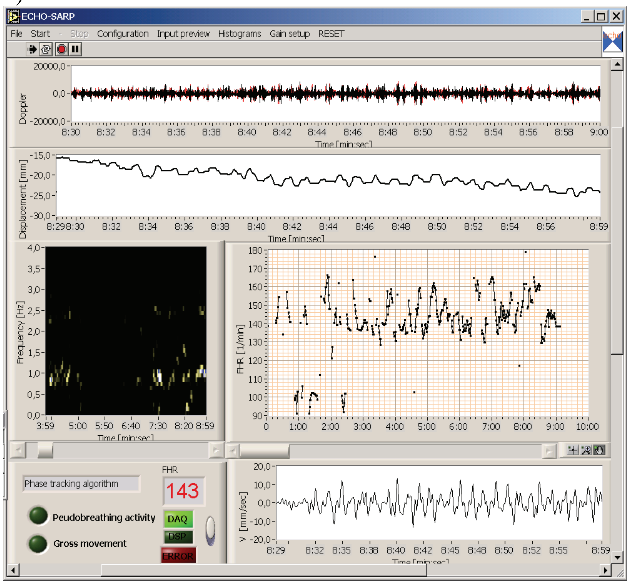


Figure 5: The main program window organization

During the ultrasonographic validation of the software, all visible on the video recordings periods of the fetal pseudobreathing activity were detected by software. A few individual fetal chest movements were missed with phase tracking algorithm. Cardiac rhythm was detected on the basis of Doppler data in the majority of the recording time but there were difficulties to detect cardiac rhythm during the gross fetal movements [8].

a)



b)

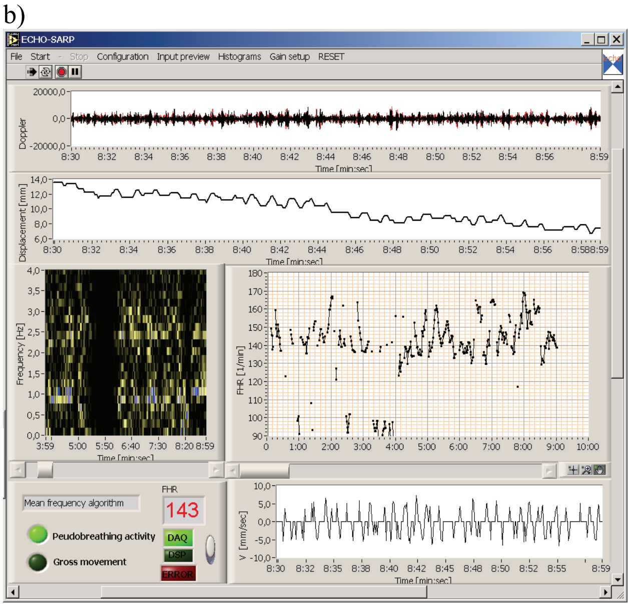


Figure 6: The results analysis of the same signal segment a) the phase tracking algorithm, b) the mean Doppler frequency estimation algorithm

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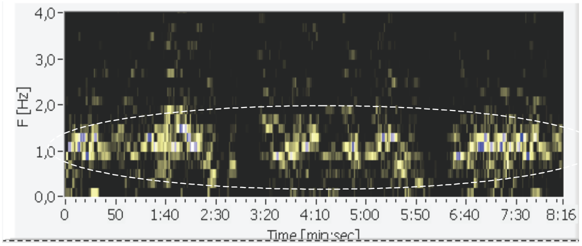

Figure 7: Spectrogram of velocities of fetal movement, maximum between 1-1.5Hz indicates pseudobreathing activity periods (the mean Doppler frequency estimation algorithm)

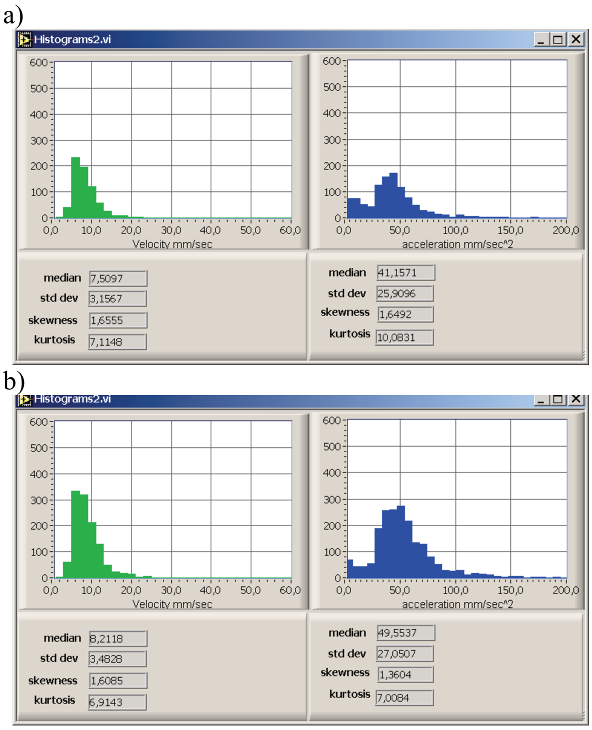

Figure 8: The histograms of velocities and accelerations after 15 minutes fetal activity examination of two non complicated pregnancies a) low pseudobreathing activity was observed less than 1 min. during the examination period, b) over 10 minutes pseudobreathing activity during the examination period

Discussion

The proposed system is a promising and interesting tool for obstetrics, as it enables automatic detection and quantification of fetal motor activity and provides data for further activity classification.

The two algorithms for displacements and velocities estimation were implemented. The mean frequency algorithm allows calculating velocities even for low S/N ratio Doppler signals [9]. The phase tracking algorithm has better temporal resolution but is noise and interference sensitive. The displacement trace resulting from the phase tracking algorithm showed spurious detail and drift, thus, application of a drift elimination procedure (filtering) was necessary.

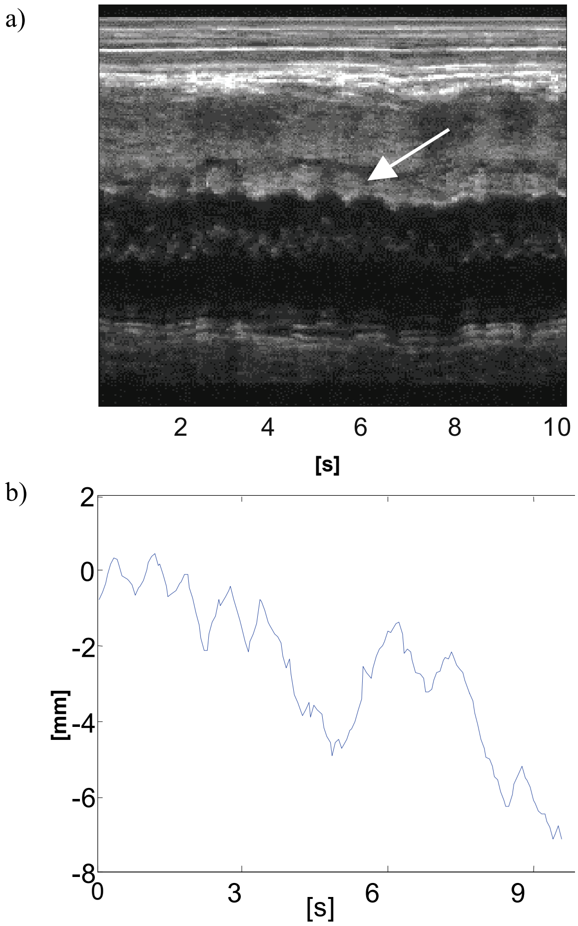

Figure 9: Ultrasonographic validation process a) 10 sec long M-mode image (fetal chest structure movements visible), b) corresponding displacement pattern (phase tracking algorithm)

Table 1: Example feature vector

	Feature	Type of data	Example
Histogram of velocities	median	number	7,05
	Standard deviation	number	3,15
	Skewness	number	1,65
	kurtosis	number	7,12
Histogram of accelerations	median	number	41,16
	Standard deviation	number	25,90
	Skewess	number	1,65
	kurtosis	number	10,84
Pseudobreathing activity occurrence		logical value	true
Examination time (sec)		number	840

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The pseudo-breathing movement episodes are of clinical significance if they last few seconds [10]. Therefore, the approach based on analysis for 5 seconds long data window is satisfactory from the medical point of view. The detection of pseudobreathing activity does not require the displacement (phase) data as the input. The movement velocity data free from DC component and drift is sufficient. Therefore, the mean frequency approach seems more suitable for pseudobreathing episodes detection than the analysis of phase of the analytical Doppler signal.

The fetal condition affects fetal behaviour, presence of fetal pseudobreathing movements, global movements and their properties [10,13,14]. Therefore, description of fetal activity with histograms of velocities and accelerations and parameters of these histograms seems justified.

The CW device used to the FHR detection may result in some problems when fetal gross body movements occur. A solution to this problem would be using a dual-gate PW system, currently under development.

The next step is the collection of sufficient amount of clinical data to enable the automatic classification of fetal activity based on feature vector.

Acknowledgements

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References

[1] AFANA F., KALUZYNSKI K., PALKO T. (1998): ‘Continuous wave ultrasonic system for detection and analysis of ultrasonic Doppler signals of fetal activity’. *Polish J. Med. Phys. Eng*.,**4(1)**, pp. 31-37

[2] BESINGER R.E., JOHNSON T.R.B. (1989): ‘Doppler recordings of fetal movement: clinical correlation with real-time ultrasound’, *Obstet. Gynecol.,***74**, pp. 277-280

[3] GOOVAERTS H.G, COHEN D, DRIPPS, J.H, ROMPELMAN O, JONGSMA H.W. (1990): ‘A comparative experimental study of fetal phono- and movement- sensors’ - *Amsterdam, Cambridge and Edinburgh. Clin. Phys. Physiol. Meas*.,**12**, pp. 55-64

[4] KUPKA T., JEZEWSKI J., MATONIA A., WROBEL J. ET AL., (2004): ‘Evaluation of fetal movement activity recorded via ultrasound FHR transducer’, *Arch. Perinatal Med.*, vol. **10(2)**, pp. 21-27

[5] KALUZYNSKI K., BERSON M., POURCELOT L., PALKO T. (1993): ‘Detection of fetal breathing and cardiac signals and rhythms in the ultrasonic Doppler signal recorded on the surface of the maternal abdomen’, *Med. Bio . Eng. Comput.*,**31**, pp. 405- 411

[6] KARLSSON B., FOULQUIERE K., KALUZYNSKI K., TRANQUART F, FIGNON L., POURCELOT D., POURCELOT L., BERSON M. (2000): ‘The DOPFET system - a new ultrasonic Doppler system for monitoring and characterization of fetal movement’, *Ultrasound Med.Biol*.,**26(7),** pp. 1117–1124

[7] KRET T., KALUZYNSKI K. (2003): ‘Data acquisition and analysis system for ultrasonic Doppler signals of fetal motor activity’, Proc. of Int. Conf. Mechatronics, Robotics and Biomechanics 2003, Hrotovice, Czech Rep., 2003, p. 161-162

[8] KRET T., KALUZYNSKI K. (2004) ‘Ultrasonographic validation of the software system for online analysis of ultrasonic Doppler signals of fetal activity’. *Elektronika*,**8-9**, pp. 127-129

[9] KRET T., KALUZYNSKI K., LESNIAK B. (2005): ‘Algorithms used in ultrasound Doppler fetal motor activity monitoring’. Proc. of Int. Conf. Mechatronics, Robotics and Biomech. 2005, Třeš, Czech Rep., 2005,

[10] MANNING F.A., PLATT L.D., SIPOS L. (1980): ‘Antepartum fetal evaluation: development of fetal biophysical profile’ - *Am. J.Obstet. Gynecol*.,**136**, pp. 787-795

[11] MAEDA K. ET AL. (1997): ‘Evaluation and standardization of fetal monitoring. Report of the FIGO Study Group on the Assessment of New Technology’ *Int. J. Gyn. Obstet*., **59**, pp 169-173

[12] MC NAY M.B, FLEMMING J.E.E. (1999): ‘Forty years of obstetric ultrasound 1957-1997: from A-scope to three dimensions’. *Ultrasound Med. Biol.,***25**, pp.3-56

[13] PRECHTL H.F. (1997): ‘State of the art of a new functional assessment of the young nervous system. An early predictor of cerebral palsy.’ *Early Hum. Dev.*,**50(1**), pp. 1-11

[14] SIVAL D.A., VISSER G.H.A., PRECHTL H.F.R. (1992): ‘The effect of intra-uterine growth retardation on the quality of general movements in the human fetus.’ *Early Hum. Dev.,***28**, pp. 119-132

[15] YAMAKOSHI Y., OTAKI H., SHINOZUKA N., MASUDA H. (1996): ‘Internal tissue displacement measurement based on ultrasonic wave Doppler signal detection and its application to fetal movement monitoring’, *Ultrasonics,***34**, pp. 769-775

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