Determination of Fetal Breathing Movement Using Phonocardiography

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"There can be no greater love, no more persistent activity, no more tiring work or restlessness during the day and the night, than the care of mothers for their child."
∼Péter Pázmány∼

Introduction

For more than 40 years, the ultrasound has been one of the most advanced examination methods in the field of fetal monitoring. However, the ultrasound-based measurements can be used under medical supervision, for a limited length of time and primarily in a hospital. In contrast, it is necessary to apply assessment methods, like CTG measurements, that are capable of fetal activity monitoring, even at home. When ultrasound does not provide a clear answer about fetal activity, these types of measurements can be important for the purpose of a presumed diagnosis. The 24-Hour Holter monitoring is already widespread in cardiac diagnostics, which serves a similar purpose, and it makes a long-term measurement available that would also be too difficult to carry out in a hospital.

Owing to the increasingly rapid development of technology, not only the results of complex detection devices will become easier to evaluate, but even more accurate measurement results are also obtained via simple assessment methods. Today, an average cell phone operates at a 2.7 GHz clock speed. The technology has developed extremely lot in recent decades, based on the fact that 50 years ago the processor of Spacecraft On-Board Computer operated at 2 MHz clock speed to land on the Moon. What is this huge computing capacity enough for? In the age of artificial intelligence, data processing and data mining are perhaps among the biggest challenges. However, there are many cases when the learning algorithms themselves are not capable of providing a complete solution. There are two basic conditions of machine learning: the first is to have a large

enough set of test data that adequately covers the examined field, and the second is to keep the uncertainty of the measured data below the acceptance threshold of the evaluated data.

In the case of fPCG signals, the determination of Fetal Breathing Movement (FBM) is a complex assessment method that can only rely on the basic features, which are also resulting clearly from the physical background of the acoustic signal. The most important physical features of FBM include the starting points of the unique breathing movement, which indicate the contraction of the fetus's diaphragm; the turning points, which indicate the relaxation of the diaphragm; the relative position of the starting points; the frequency spectrum of the phonographic signal; and the dynamic nature of breathing movement, which are determined by the accelerations and decelerations of the movements. The main goal of my research was to use fPCG-based measurements to develop a non-invasive, low-cost and reliable assessment method that makes a more efficient monitoring of fetal activity available, even at home [1]–[11].

Methods

Overview of earlier studies

FBM is an important index of the Biophysical Profile (BPP). We have known about the existence of FBM for more than 130 years [12], [13], and its significance and importance has also been confirmed by other studies [14]. Initially, the FBM measurements were carried out with simple mechanical motion sensors on the maternal abdominal wall that made it possible to monitor this type of motion. Information obtained in this way is very poor, and it can indicate only the formation of the motion. In the case of periodic signals, it can be supposed that it is not induced by a general motion (like body or limb rotation), but rather it relates to the FBM. The FBM could be registered in this way, although information about its formation, role, and importance was severely limited.

The first relevant information source about FBM is *Patrick et al.* [15], who identified first the occurrence and duration of this kind on motions, and they were able to distinguish them from other fetal movements like body rotation or head and limb movements. The study of *Junge and Walter* [16] went a step further, which investigated the relationship between sleeping states and FBM. The study of *Noguchi and Walter* [17] discussed these same questions, and they explored the relationship between the two mentioned fetal actions, but their results have not been not fully confirmed subsequently. With the development of ultrasonic measurements, it has become possible to complete much more accurate examinations than before,

which was exploited by *Andrews et al.* [18] in their research. They determined the size and variability of the measurement with mm resolution.

The FBM slowly has become an essential index of fetal health as a result of all these early measurements, although the cause of FBM was not clarified. This is indicated by the fact that the number and duration of FBMs have become the part of the biophysical profile. Later, the regular measurement of FBM has also become a required test. However, this examination was very difficult to carry out because of the random occurrence of the breathing movement, which also considerably extended the investigation time. Independently from each other, *Berger and Trigg* [19], *Talberg et al.* [20] and *Ansourian et al.* [21] made efforts to solve this problem, who measured the signal of the mechanical movement with a piezo instrument placed on the maternal abdomen. Another improvement was made by *Goovaerts et al.* [22], who measured the generated current on a coil formed on a flexible membrane, while it was moving in the magnetic field in the sensor on the mother's belly. Both sensors were revolutionary at the time, but it was shown that despite their further refinement, they provided only an uncertain image about the motion. Furthermore, they were unable to show the accurate details e.g. the exact time function of the movements or the intermediate stops. The inconvenience of potentially extremely long measurements for the mothers was also problematic.

Nevertheless, extensive research was started to investigate fetal movement. Among other things, the study of the relationship between FBM and fetal heart function came into view again with the work of *Moczko* [23] and *Foulquiere* [24]. *Florido et al.* [25] also made efforts to meet challenges in this topic at same time, but they already used ultrasonic measurement for this purpose. The FBM research was apparently boosted thanks to the novel advanced signal processing techniques including the variety of frequency and spectrum processing algorithms, whose primary purpose was to detect the occurring diseases already in fetal age. The *Ansourian* [21] and *Dornan-*

led research group [26] in the field of Intrauterine Growth Restriction (IUGR) also played an important role in FBM research. Finally, the work of *Cousin* [27] and the research of *Akay and Szeto* [28], should be mentioned, who opened new perspectives in the biomedical signal processing using the Matching Pursuit (MP) method. These included the use of the fuzzy method [29]. Regarding the fetal movements, the issue of hiccups arouse early [30], as well its relation to FBM and their differences [31]. Finally, a completely new question is the possible link between FBM and Sudden Infant Death Syndrome (SISD) [32].

Methods of my study

Initial research in the field of phonography

In the field of phonography, I first studied the adult heart sounds. Based on the public database of the MIT Laboratory for Computational Physiology, I had access to PCG measurements, which were verified and annotated by medical specialists that made possible to examine abnormal heart sounds. The pathological cases that I examined included various heart valve defects, coronary artery disease, mitral valve prolapse, mitral regurgitation, aortic stenosis, and valve surgery.

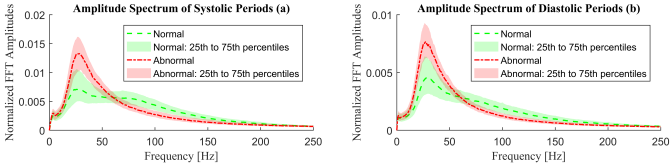

Figure 1. Mean amplitude spectra of systolic and diastolic intervals for the training database [6]

Using the SVM (Support Vector Machine) method and time-frequency analysis of the systolic and diastolic sections, I could determine the abnormal heart sounds with high confidence on different

Test set			Training database		
Se(%)	**Sp(%)**	**MAcc(%)**	**Se(%)**	**Sp(%)**	**MAcc(%)**
87.1%	74.8%	81.0%	**97.6%**	84.2%	**90.8%**
77.2%	85.2%	**81.2%**	91.7%	82.2%	87.0%
74.4%	**87.8%**	81.1%	71.1%	**86.6%**	78.9%

Table 1. Results of classification on different dataset [6]

and independent data sets. Using the morphological features of the time and frequency domain of the heart sounds, I have identified the normal and the abnormal signals with **80.28%** final modified accuracy (MAcc) on a thousand-strong pattern test set, which was independent from the training set.

During the studying of adult heart sounds, the professional eperience has broadened my horizons in the field of medical signal processing, which I have utilized in my further research.

Fetal Breathing Movement detection in the phonograms

The determination of FBM was based on a synchronous measurement arrangement that helped to point out the peculiarities of acoustic signals in the field of FBM. I carried out my measurements with a *Fetaphon 2000* device and a *Samsung UGEO H60* ultrasound device for fetal monitoring. I transmitted my fPCG measurements directly via *Bluetooth* communication to a laptop, and at the same time I recorded the results of the ultrasound measurements using a video recorder (Fig. 6).

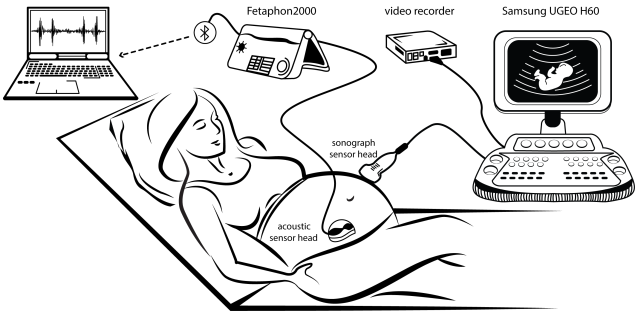

Figure 2. Complete setup for measurement and validation [2]

The examinations were carried out in collaboration with St. Margaret's Hospital, where I examined more than 50 pregnant mothers using my synchronous measurements. The examined fetuses were in the 3rd trimester, and I also made measurements directly in the weeks before the birth. I evaluated the results obtained by this method by complex test methods. I also evaluated the video signals. I selected those parts of the recordings where the sonograph had previously indicated breathing motion. Afterwards, I determined the FBM waves, which indicate the contraction and relaxation of the diaphragm, using image processing methods. I conducted a comprehensive research in the time and frequency domain to evaluate the phonographic signals.

Using the obtained FBM waves from the ultrasound videos, I was able to verify the starting points of the FBM in the phonographic signals. Based on these measurements, I could identify the main components of the frequency spectrum, and I could also characterize the dynamic changes of the FBM. Thanks to the detailed research, our previous knowledge about FBM has been expanded.

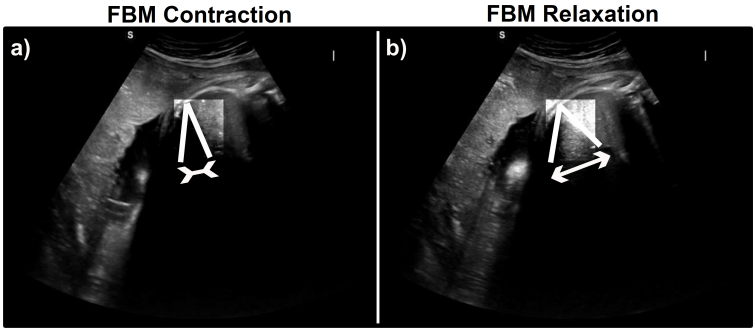

Figure 3. Contraction and relaxation of the diaphragm in the sonographic measurements

In my dissertation, I present a novel assessment method that facilitates the determination of FBM in the phonographic signals in

addition to the detection of FHR and heart murmurs using an easily accessible fPCG-based home monitor. I visualized the result of my implemented algorithms with different versions of Matlab.

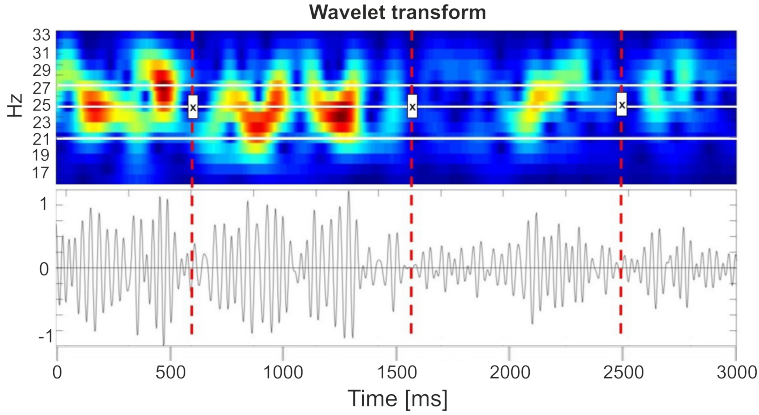

Figure 4. Wavelet analysis of FBM episodes in phonographic signals

Between the episode a short, minimum-zones (20-30 ms) is detectable (550 ms, 1550 ms, 2500 ms), where a phase change also appears. However, FBM episodes change chaotically, as can be clearly seen between 1500 and 2500 ms.

Thousands of FBM episodes have been investigated to get an exact picture about their ongoing changes. Although this area has long been researched, FBMs have not yet been studied in such detail. The main value of this study in contrast to the previous general FBM detection tests is that we can get a comprehensive assessment about the episode changes according to the different gestational ages and the sex of the fetus. Thanks to the large number of measurements, several previous assumptions have been proved.

The FBM episodes were evaluated in different stages of the last trimester, which also showed significant differences according to sex

(see Fig. 5). However, it is important to emphasize that this research is still in the initial phase, but we can consider this data representative.

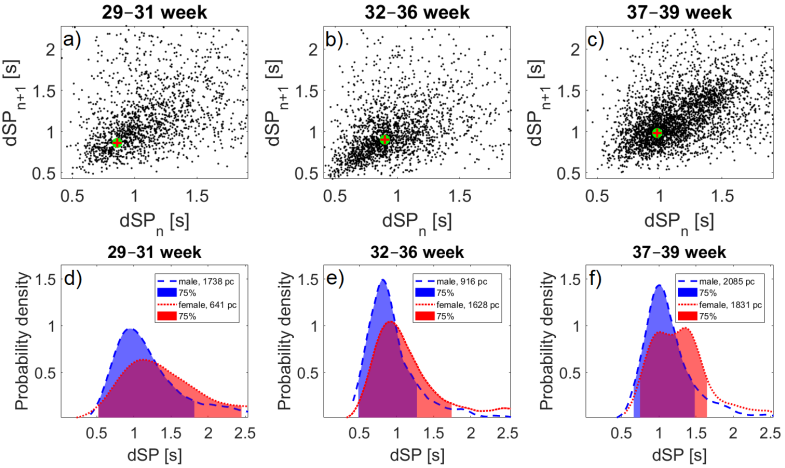

Figure 5. This figure represents the time intervals between the FBM episodes according to sex and the different gestational ages. The dSP means the distance between two episodes, which is equal to the length of the episode in most cases, especially at the end of the last trimester. For longer intervals, a shorter break is added to the episodes. The subfigures a)–c) represent the Poincaré-like data, where the most characteristic length of FMB intervals is about 1 sec. The subfigures d)–f) represent time intervals by sex. At the beginning of the last trimester, there are much more uncertain FBM episodes, but there is a significant difference between male and female fetuses, too. In the case of females, there are many more breaks between the FBM episodes [2].

	No. Episode Groups (pc)			No. Episodes (pc)			Percentage Distribution of Episodes (%)			Mean±SD No. Episodes (pc)		
Weeks	**29–31**	**32–36**	**37–39**	**29–31**	**32–36**	**37–39**	**29–31**	**32–36**	**37–39**	**29–31**	**32–36**	**37–39**
MALE												
1 episode	613	302	480	613	302	480	35,3	33,0	23,1	1	1	1
2–5 episode	283	125	301	777	336	833	44,7	36,7	40,0	2,7 ± 1	2,7 ± 0,9	2,8 ± 1
6–10 episode	26	14	51	176	94	359	10,1	10,3	17,2	6,7 ± 1	6,7 ± 0,7	7 ± 1
10< episode	12	12	26	171	183	410	9,8	20,0	19,7	14,3 ± 5,5	15,3 ± 5,9	15,8 ± 8,2
FEMALE												
1 episode	323	555	793	323	555	793	50,7	34,1	43,4	1	1	1
2–5 episode	99	241	202	249	665	563	39,1	40,9	30,8	2,5 ± 0,9	2,8 ± 1	2,8 ± 1
6–10 episode	6	41	37	42	293	251	6,6	18	13,7	7 ± 0,9	7,2 ± 1,1	6,8 ± 1
10< episode	2	9	14	23	114	222	3,6	7	12,1	11,5 ± 2,1	12,7 ± 3,6	15,9 ± 10,9

Table 2. The FBM episode groups' formation during the different gestational ages in the last trimester of males and females fetuses.

New scienticfic results

In the following, I present my new scienticfic results in five thesis groups.

I. *Investigation of adult phonographic signals*

I have examined the abnormal cases in adult phonographic records on the public database of the MIT Laboratory for Computational Physiology to determine the characteristics of pathological features. I have examined more than 300 cases, which have been also annotated by foreign medical specialist for this purpose. I have separately evaluated the systolic and diastolic time intervals. Their frequency spectra have been narrowed to 25–35 Hz, where the amplitude spectra of abnormal heart sounds were significantly higher than in normal cases. Based on this, I have created a much simpler and more efficient procedure, in contrast to the previously used segmentation methods, which is especially advantageous in the detection of heart valve disorders. Using the morphological features of the time and frequency domain of the heart sounds, I have identified the normal and the abnormal signals with 80.28% accuracy on a thousand-strong pattern test set, which was independent from the training set [6].

II. *Investigation of Fetal Breathing Movement using sonographic and phonographic measurements*

II.1. In the field of fetal breathing movement research, I carried out novel synchronous measurements on pregnant women to determine the Fetal Breathing Movement (FBM). I combined the measurement results of a 3D ultrasound machine and a passive fetal phonocardiography (fPCG) device placed on the maternal abdomen (Table 3). These two kinds of data, on the one hand, complement each other – thus increasing measurement accuracy; and on the other hand, allow for defining further characteristics of the FBM. More than 50 pregnant women were involved in the measurements. I defined the starting points of the FBM elements (episodes) in the phonographic signals (Fig. 6). Based on the ultrasonic video signals and using the photogrammetry method, I accurately recorded the appearance of a short-term, approximately 20-30 ms long pause, which follows the evoked contraction and relaxation of diaphragm. Based on this, I have developed a completely new method for FBM detection ([1], [2], [4], [9]).

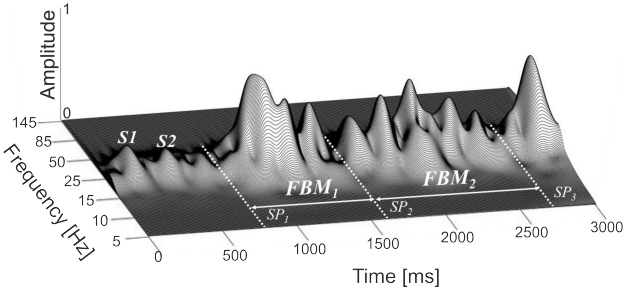

Figure 6. Time and frequency analysis of FBM episodes in 3D

Sex	No.	Mean fetal age	Mean fetal weight	Last meal	Gross FM	Gross FBM
female	25	34,5 week	2240 g	2 hour	56 min	113 min
male	25	33,7 week	2380 g	1,8 hour	77 min	91 min

Table 3. The main results of synchronous measurement

II.2. I have also shown that the length of both episodes and epochs is strongly dependent on other factors such as fetal and maternal health condition, food intake and fetal development, which change continuously during pregnancy. Furthermore, I have shown that although the episodes themselves can be considered chaotic signals, the Lyapunov exponents do not clearly define either the starting points of FBM episodes or the diaphragmatic relaxation, although the Lyapunov exponents take a higher value compared to FBM-free sections (Fig. 7). Evaluating this, I have proved that the intensity curve of the contractions in the fPCG signals is directly proportional to the magnitude of the exerted force ([1]–[4]).

I have determined the chaoticity of the FBM episodes using the calculated λ Lyapunov-exponents in the N time window [33]:

$$\lambda = \frac{1}{(t_N - t_0)} \sum_{k=1}^{N} log_2 \frac{L'(t_k)}{L'(t_k - 1)} \tag{1}$$

Figure 7 shows that the standard deviation of the exponents of FBM episodes is significantly larger than that of FBM-free episodes.

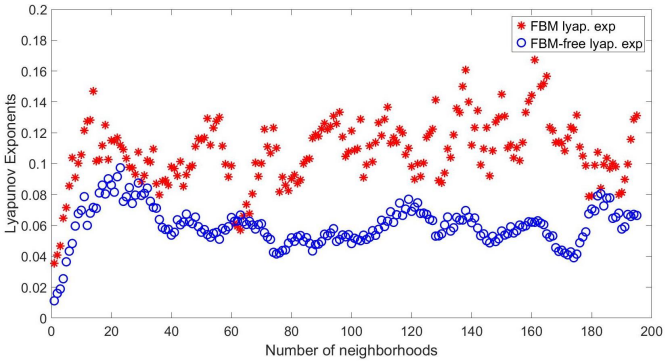

Figure 7. Average Lyapunov-exponents of FBM and FBM-free episodes [3]

III. : *Time and frequency analysis of fetal breathing movement*

III.1. I have proved that FBMs can be detected in the phonographic signals in the region of 15–35 Hz most effectively (Fig. 6). Furthermore, I have shown that the intensity change, periodicity, and frequency spectrum of FBM significantly differ from other fetal and maternal sounds, such as sounds of hiccups, trunk rotation or limb movements, maternal and fetal heart sounds, and other gastroenteric sounds; consequently, FBM episodes can be determined with high confidence ([1]–[4]).

III.2. I have shown that if I select the phonocardiographic signal with a filter set to the dominant frequency of the FBM, a well-distinguishable intensity change can be noticed in the signal, where the intensity is characterized by a minimum-zone (Eq. 2). The minimum-zone of FBM is followed by a relatively steep rise of intensity, which indicates the diaphragmatic contraction (Eq. 3). Furthermore, I showed that in the minimum-zone of

the FBM, a phase change can be additionally detected in the filtered signal, which also indicates the contraction of the diaphragm, and possibly its relaxation (Eq. 5, [3], [4]).

III.3. I have shown that one of the most characteristic data of FBM episodes is the global intensity (Eq. 4). Based on this, as well as on the accurate knowledge of physical characteristics, I have determined the later used hypothetical starting points of the FBM episodes with an acceptance limit (Eq. 6, [3], [4]).

I have defined the equations of the III. Thesis point as follows

The acceptance limit is defined by four features, where the first one is based on d_1 (section between $i_1 - i_2$) $\approx \lambda$ (the wavelength at a given frequency) for the length of the minimum-zone, which is given as the sum of the absolute values of the residual signal intensity (divided by the length of the section).

$$F_{1,m} = \frac{\sum_{i=i_1}^{i_2} \mathrm{abs}(s_m[i])}{d_1} \tag{2}$$

This amount is a summary of a short period. The rise of the absolute values after the minimum zone is given in the same way, where $d_2 = (i_3 - i_2)$.

$$F_{2,m} = \frac{\sum_{i=i_2}^{i_3} \mathrm{abs}(s_m[i])}{d_2} \tag{3}$$

This section starts at i_2 and marks the "enclosed" rising part.

The third condition is the measured intensity during the hypothetical episode, where $N = 1$ *sec* and d_3 =Fs.

$$F_{3,m} = \frac{\sum_{i=i_2}^{N} \mathrm{abs}(s_m[i])}{d_3} \tag{4}$$

I have defined the phase shift of the minimum zone as follows:

$$F_{4,m} = \mathrm{arctg}(\phi_0) - \mathrm{arctg}\frac{\sum_{i_1}^{i_2} s_m(i)\sin(2\pi f_m k i)H(w)}{\sum_{i_1}^{i_2} s_m(i)\cos(2\pi f_m k i)H(w)} \tag{5}$$

where f_m is the mean of the given frequency subband and $H(w)$ is the Hann-window function with a given width and at the given time.

I have defined the $G_{H,m}$ acceptance limit for the test-frequency of the episodes as follows:

$$G_{H,m} = w_1/F_{1,m} + w_2 F_{2,m} + w_3 F_{3,m} + w_4 F_{4,m} \tag{6}$$

where w_{1-4} denotes the weight factors of the FBM features.

IV. *The application of a Hidden Markov Model for FBM determination*

Based on the large number of measurements, I have proved that the Markov processes are suitable to examine the FBM signals. I have created a Hidden Markov Model to determine the actual dominant test-frequency bands of FBM signals, thus excluding the remaining frequency sub-bands. As a result, I have made the computational work for the detection of minimum zones significantly more efficient. [1], [3].

I have defined the equation of the IV. Thesis point as follows

Let $F^t(\tau)$ be a Markov chain for a given time-window $t \in \mathbb{N}$ with state-space $\mathbf{S}^F$. The time-variable of the Markov chain $\tau \in \{1, \ldots, \text{max. window-size}\}$. The length of the time-window t is determined by a fixed window-size, which must be between 1500-3500 sample in the case of 333 Hz sampling frequency.

$$\mathbf{S}^F = \{\phi_1, \phi_2, \ldots, \phi_n\}, n \in \mathbb{N} \tag{7}$$

The distribution of the intervals between the minimum-zones were classified into four different states. Let $D^t(\tau)$ be a HMM for a given time-window $t \in \mathbb{N}$ with state-space $\mathbf{S}^D$. The time-variable of the HMM $\tau \in \{1, \ldots, \text{max. window-size}\}$.

$$\mathbf{S}^D = \{\delta_1, \delta_2, \delta_3, \delta_4\} \tag{8}$$

where $0 \leq \delta_1 < 0.3$ sec, $0.3 \leq \delta_2 < 0.75$ sec, $0.75 \leq \delta_3 < 1.2$ sec, $1.2 \leq \delta_4$ sec. Let us denote transition matrix of the Markov chain F^t by $\underset{=}{A}$, that is, the (i, j) elements of $\underset{=}{A}$ are

$$\begin{aligned} &(\underset{=}{A}(t))_{i,j} := \mathbb{P}(F^t(\tau) = \phi_i | F^t(\tau - 1) = \phi_j) \\ &i, j \in \{1, .., n\}, n \in \mathbb{N}, \quad \tau \in \mathbb{N} \end{aligned} \tag{9}$$

The $\underset{=}{A}$ derives from transition of minimum-zones at the different test-frequencies, namely the interesting changing part of fetal activity can be characterized by the minimum-zones. On the other hand, the relative position of minimum-zones were investigated at the different test-frequency bands. Let us denote the transition matrix of the HMM D^t by $\underset{=}{B}$, that is the (i, j) elements of $\underset{=}{B}$ are

$$\begin{aligned} &(\underset{=}{B}(t))_{i,j} := \mathbb{P}(D^t(\tau) = \delta_i | F^t(\tau) = \phi_j), \\ &i \in \{1, .., 4\}, j \in \{1, .., n\}, n \in \mathbb{N}, \tau \in \mathbb{N} \end{aligned} \tag{10}$$

$\underline{\underline{B}}$ describes the probabilities of interval-states between the minimum-zones at the different test-frequencies.

Stationarity of these transition matrices were inspected for each time-window in order to apply an HMM. According to the Bayes-theorem, the conditional probability of the dominant test-frequencies is given by the occurrance of the interval-states. Let $\underline{\underline{A}}(t)$, $\underline{\underline{B}}(t)$, $\underline{\underline{C}}(t)$ be matrix-valued function at time t, where

$$\begin{aligned}
\big(\underline{\underline{A}}(t)\big)_{ij} &= A_{ij}(t), \quad i,j \in \{1,\dots,n\}, n \in \mathbb{N} \\
\big(\underline{\underline{B}}(t)\big)_{ij} &= B_{ij}(t), \quad i \in \{1,\dots,n\}, n \in \mathbb{N},\, j \in \{1,\dots,4\}, \\
\big(\underline{\underline{C}}(t)\big)_{ij} &= C_{ij}(t), \quad i \in \{1,\dots,n\}, n \in \mathbb{N},\, j \in \{1,\dots,4\}
\end{aligned} \tag{11}$$

and

$$\begin{aligned}
\big(\underline{\underline{C}}(t)\big)_{i,j} &:= \mathbb{P}\big(F^t(\tau) = \phi_i | D^t(\tau) = \delta_j\big) = \\
&= \frac{\mathbb{P}\big(D^t(\tau) = \delta_j | F^t(\tau) = \phi_i\big)\mathbb{P}\big(F^t(\tau) = \phi_i\big)}{\mathbb{P}\big(D^t(\tau) = \delta_i\big)}
\end{aligned} \tag{12}$$

where $i \in \{1,..,n\}$, $j \in \{1,..,4\}$, $\tau \in \mathbb{N}$ and

$$\mathbb{P}\big(D^t(\tau) = \delta_j | F^t(\tau) = \phi_i\big) = B_{ij}(t) \tag{13}$$

$\mathbb{P}\big(D^t(\tau) = \delta_i\big)$ probability estimated by

$$\widehat{\mathbb{P}\big(D^t(\tau) = \delta_i\big)} = \frac{\sum_{j=1}^{4} B_{ij}(t)}{\sum_{i=1}^{n}\sum_{j=1}^{4} B_{ij}(t)} \tag{14}$$

finally $C_{ij}(t)$ probability matrix is estimated by

$$C_{ij}(t) \approx \widehat{C}_{ij}(t) = \widehat{B}_{ij}(t) \frac{\mathbb{P}(F^t(\tau)|\phi_i)}{\widehat{\mathbb{P}\big(D^t(\tau) = \delta_i\big)}} \tag{15}$$

$$i \in \{1, \ldots, n\}, j \in \{1, \ldots, 4\}, n \in \mathbb{N}, \quad \tau \in \mathbb{N}$$

The $C_{ij}(t)$ probability matrix can predict the next dominant frequency-band at every t time. The HMM has a short-term memory for epoch detection, which stores the probabilities of the ranked test-frequencies. The state-transitions of the dominant test-frequencies lead up to the clustering of minimum-zones. All minimum-zones of dominant test-frequencies are used for the clustering.

V. *Procedure for FBM determination*

I have developed a new complex method using phonographic signals to determine the FBMs that can certainly be applied in medical practice. The steps of the method are:

- **(a) Narrowing the measured broadband phonographic signals in the 20–30 Hz frequency region and then splitting it into test-frequencies (sub-bands).**
- **(b) Searching for minimum-zones in each frequency band based on predefined FBM characteristics.**
- **(c) Merging the minimum-zones using clustering, and thus determining the FBM starting points, as well as separating the short episode sequences.**
- **(d) Formation of standard FBM episode groups (short epochs) based on the obtained FBM starting points.**
- **(e) Building up and evaluation of the whole FBM epoch [3].**

Possible Applications

The determination of FBM offers a huge opportunity for the future. In the USA, fetal activity is measured by antepartum CTG, or NST (Non-Stress Test). The FBM determination is not only a new scientific advancement in terms of BPP, but may also play an important role in the rapid and efficient measurement of fetal activity.

Furthermore, the procedure that I have developed can contribute to state-of-the-art home fetal monitoring during high-risk pregnancies, providing safely an image about the fetal development for medical doctors using telecommunications. In addition to the previously determined FHR, heart murmurs, and fetal hiccups, fetal monitoring has been complemented with a much complex assessment now, which may even prove to be a landmark for the future.

Concerning further research, a more accurate image will be accessible about the last period of the pregnancy. It might be discovered what causes the previously unknown onset of birth. The respiratory development will be predictable in the case of preterm infants. The causes of Sudden Infant Death Syndrome (SIDS) and fetal distress will be much clearer for us. In the last weeks of the pregnancy, fetal development and any growth abnormalities (like Intrauterine Growth Restriction, IUGR) will be traceable. Also a number of uncertain things that have not yet been substantiated previously will be better understood.

The primary objective of my research was to determine the FBM in the phonographic signals. The future goal is that this method should be made available as widely as possible, and in this way we can save the lives of endangered fetuses and help their healthy development with the lowest risk factor.

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