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Identification of a Nonlinear Association between Components of the Electrohysterographical Signal

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***Abstract*—Electrohysterography is a method for measuring of bioelectrical potentials generated by a contracting uterus. It is used for monitoring of uterine activities mainly during a pregnancy and for prediction of an upcoming preterm labour. However, there is still unknown the best method of EHG analysis which gives clinically useful information about a uterine activity. To achieve this goal we propose to use information about nonlinear associations between EHG signals registered from an uterine fundus and an uterine cervix. The h^2 index was applied to identify these relationships. The obtained results reveal that there exists a nonlinear correlation between biopotentials generated from two parts of a pregnant uterus. Moreover, this correlation seems to be higher as a labour is upcoming. It suggests a possibility of using the h^2 index for prediction of an upcoming labour based on EHG signals.**

***Keywords*—Biomeasurements, electrohysterography, nonlinear signal analysis, h^2 index, nonlinear association.**

I. Introduction

BIOMEASUREMENTS are one of the greatest areas of electronic application in medicine and biology. Nowadays, there are two main goals leading to development of new methods and equipments in biomeasurements. The first goal is to measure such quantities which enable to recognize a human identity. The second one is measuring of biological quantities characterized a state of human organism to aid evaluation of human health. Despite the fact that dynamic development of new sensors is observed, most of research is still concentrated on well-known bioelectrical signals generated by heart (ECG), brain (EEG) or smooth skeletal muscles (EMG). Monitoring of these signals have a pivotal meaning for human life so numerously problems associated with their acquisition and analysis are solved.

Relatively lower attention is paid to signals allowing for monitoring of processes related with human reproduction. It can be presumed that this disproportion arises from historical and cultural conditions because human reproduction was always treated as a magic phenomenon too private for science investigations. Thus, application of biomeasurements in reproductive medicine and biology is still poor.

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Generally, each human reproductive process requires monitoring of two biological components: health of a fetus and health of a mother with particular attention to her reproductive system. From biomeasurements point of view monitoring of fetus health status is performed based on acquisition and analysis of fetal USG images and monitoring of fetal ECG signals [5]. Moreover, there are efforts to monitoring a fetal EEG signal but this signal is not measured in a standard obstetrical care [9].

Evaluation of anatomical and physiological states of mother reproductive system is performed basing on USG images and measuring uterine activity. Qualitative and quantitative knowledge of uterine contraction is necessary to predict a course of term labour or to predict a risk of a preterm labour.

Routinely, uterine contractions are monitored by a mechanical sensor placed on an abdominal skin of a pregnant woman This sensor measures an uterine wall deformation. Unfortunately, the sensitivity of this method is low particularly for obese women.

Thus, an alternative method for monitoring of uterine contractions is developing. Presuming that each uterine contraction is preceded by bioelectrical activity of an uterine muscle (called myometrium) we can measure these bioelectrical impulses instead of mechanical deformations. This method is called electrohysterography (EHG) and it is similar to well known electrocardiography. However, opposite to ECG there is no standard of EHG measuring and character of EHG signals is still unknown. The main goal of EHG analysis is to find such parameterization of EHG signals which enables to predict an upcoming labour activity of a pregnant uterus.

Habitually two electrodes are used to EHG measuring but multi-electrodes measuring system are proposed too [6]. Despite of at least two dimensional EHG signal is measured the proposed methods basing on Fourier or wavelet spectra, as well as nonlinear techniques usually analyzed each component of EHG signal separately [8,2,10,7]. This approach disables efficient use of information about mutual synchronization of different anatomical parts of an uterus. It is known from physiological point of view that synchronous contractions of an uterine fundus and an uterine cervix are necessary in a labour process.

Thus the goal of this paper is to propose a method for identification of an association between bioelectrical activity of an uterine fundus and an uterine cervix before a labour and during a labour. We hypothesize that this relation could be stronger as a labour is upcoming it could be used for prediction of an uterine labour activity.

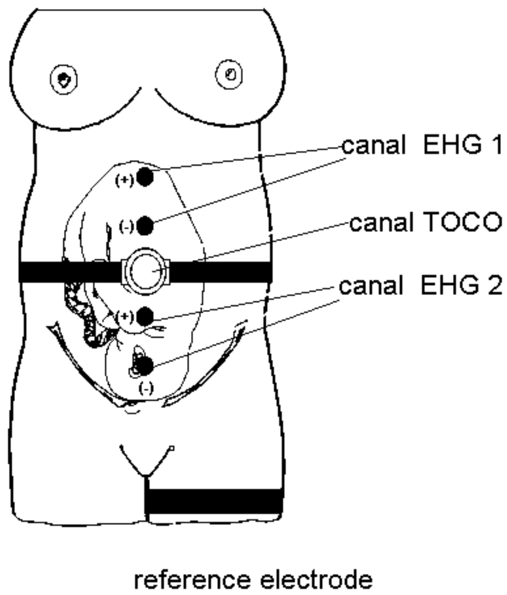

Fig. 1. Location of electrodes during EHG registration.

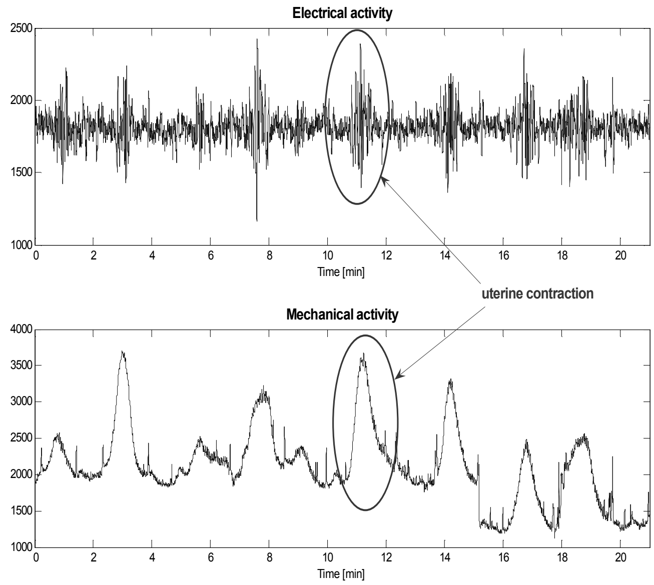

Fig. 1. An example of electrical and mechanical uterine activity during a labor.

II. EHG Signal Acquisition

Acquisition of EHG signal was made using the specialized device designed by the Institute of Medical Technology and Equipment ITAM [11]. Biopotentials generated by myometrium were registered by two Ag-Cl electrodes placed on an abdominal skin. The first electrode was placed over an uterine fundus and the second one over an uterine cervix. Because EHG signals were measured differently the reference electrode was placed on a patient's thigh. Mechanical uterine activities were also monitored by the TOCO sensor (Fig. 1).

Hardware details are described in [3]. The measured biopotentials were amplified ($k_u = 2400\,[V/V]$ and filtered by a lowpass filter (0-5Hz). The antialiasing filter was applied too. The sampling frequency was 10 Hz.

The EHG signals were registered in two groups of patients. The first group contains women waiting in a hospital for a term labour. The second group consisted of EHG signal registered during 2nd period of a physiological labour.

The Fig. 2 presents an example of mechanical and electrical uterine activity registered during 2nd period of a physiological labour. We can observe a mechanical contraction is associated with increased bioelectrical spikes.

III. Estimation of Associations between EHG Components

Conventional approaches to identification of an association between two signals use a cross-correlation function, cross-Fourier spectrum methods or a coherence function. However, this methods have two limits important from the considered point of view. All above methods allow to identify only a linear relation between analyzed signals. However, the published models describing a propagation of electrical and mechanical waves through uterine muscle fibers indicate that there are nonlinear processes [1]. Moreover, the above functions are symmetrical which disables from identification of causal relation between two signals. Knowledge about this causal relation is interesting because there are many speculations on possible directions of synchronization of uterine contractions. Therefore, we decided to use a method which estimated a nonlinear association between two signals. This method was proposed by Kalitzin *et al.* and was used to analyze relations between EEG components [4]. This index is denoted by h^2.

Let $EHG_1(t): t = 1,...N$ denote a value of EHG signal measured at the i^{th} moment at an uterine fundus. Similarly, $EHG_2(t): t = 1,...N$ denotes a value of EHG signal measured at the t^{th} moment at an uterine cervix. Then, the h^2 index is computed in the following manner:

$$h^2(EHG_1 \mid EHG_2) = 1 - \frac{\frac{1}{N}\sum_{a=1}^{M}\left[\sum_{t:\,EHG_2 \in B_a}\left(EHG_1(t) - \langle EHG_1\rangle_a\right)^2\right]}{\sigma^2_{EHG_1}}$$

$$\langle EHG_1\rangle_a = \frac{\sum_{t:\,EHG_1 \in B_a} EHG_1(t)}{N_a}, \quad \sum_a N_a = N \tag{1}$$

Figure 3 presents the scheme for selection of EHG_1 samples which correspond to the samples of EHG_2 belonging to B_a bin. $\sigma^2_{EHG_1}$ represents a standard deviation of signal EHG_1.

This index has the following interesting property. It can be proven that when two EHG components are linear correlated then the $h^2(EHG_1 \mid EHG_2) \equiv h^2(EHG_2 \mid EHG_1) \equiv 1$, [4]. Thus, an observation that

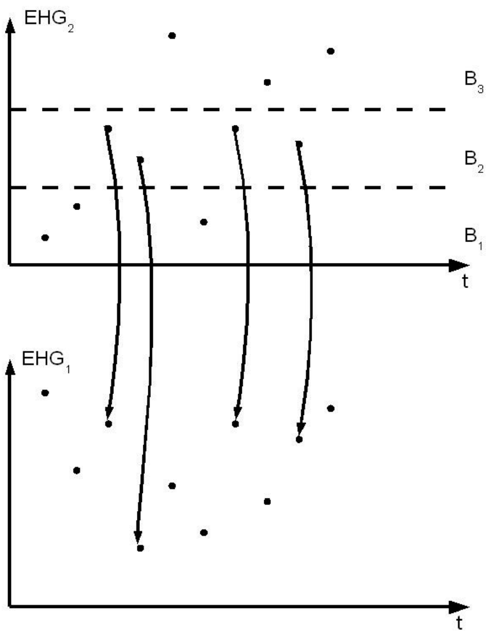

Fig. 3. The scheme of EHG samples selection used for calculation of index.

$$h^2\left(EHG_1 \mid EHG_2\right) \neq h^2\left(EHG_2 \mid EHG_1\right) \quad (2)$$

is a circumstance for identification of a nonlinear relationship between the analyzed components.

The above equation represent the fraction of the variation of the signal EHG_1 that can be "explained" by the signal EHG_2

Estimating h^2 index for various time delays between two components of EHG signal we obtained nonlinear cross-correlation sequences.

IV. RESULTS

There were estimated two indexes $h^2\left(EHG_1 \mid EHG_2\right)$ and $h^2\left(EHG_2 \mid EHG_1\right)$ to study a plausible causal relation between two components of EHG signal. Moreover, the linear cross-correlation function was estimated too.

An example of the nonlinear cross-correlation sequences are shown in Fig. 4.

The presented graphs indicate that there is a nonlinear association between two components of an exemplifying EHG signal. Moreover, these two sequences are different. The values of $h^2\left(EHG_2 \mid EHG_1\right)$ sequences are higher than the values of $h^2\left(EHG_1 \mid EHG_2\right)$ indexes.

To verify our assumed hypothesis stated that an upcoming labour could be associated with the increased nonlinear cross-correlation we computed for each EHG signal a maximal values of two nonlinear cross-correlation. Next, the obtained values were compared in two previously defined group of signals. The grouping averaged values are shown in Fig. 5, 6, 7.

Application of the nonparametric Mann-Whitney test shows that differences in the maximal values of $h^2\left(EHG_2 \mid EHG_1\right)$

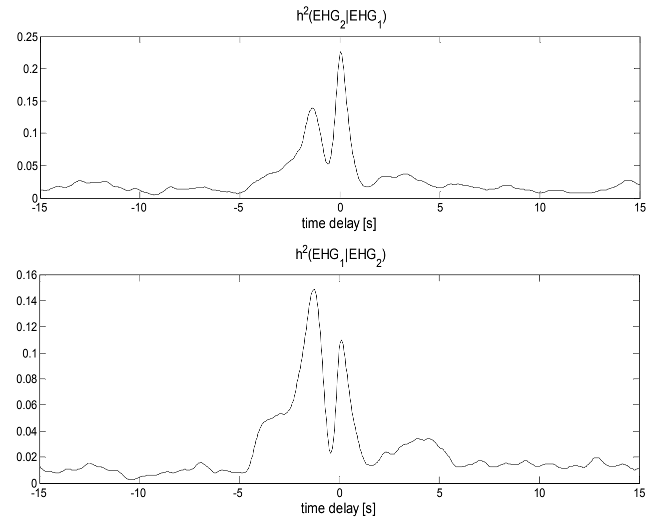

Fig. 4. An example of nonlinear cross-correlation sequences estimated using h^2 indexes.

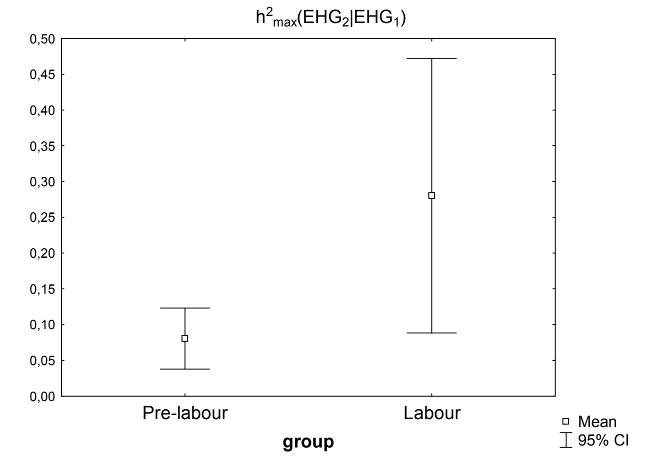

Fig. 5. Grouping averaged values of maximal cross correlation.

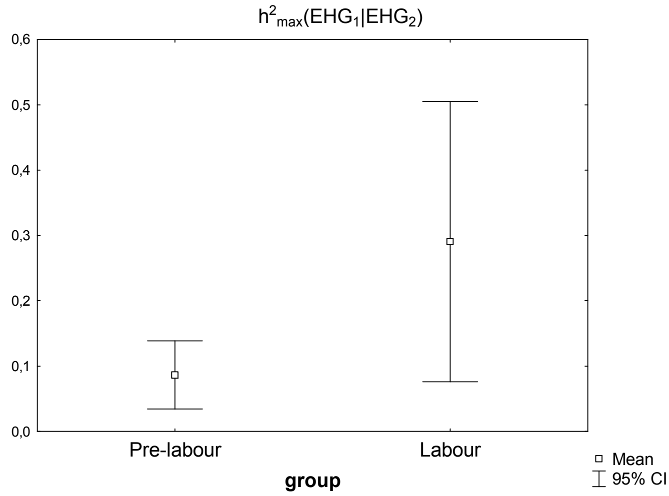

Fig. 2. Grouping averaged values of maximal $h^2\left(EHG_1 \mid EHG_2\right)$ cross correlation.

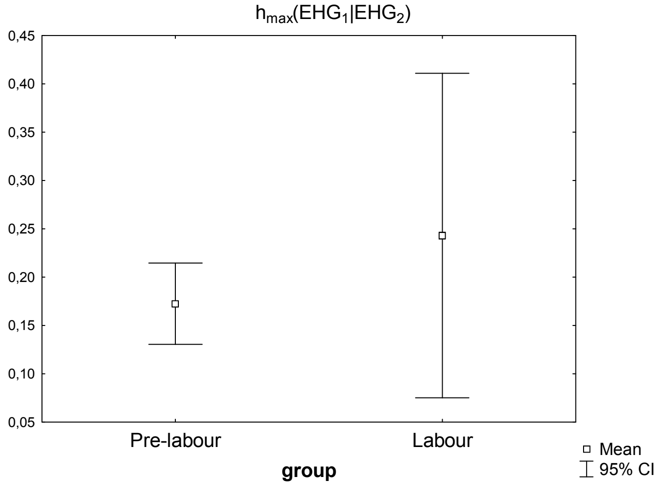

Fig. 7. Grouping averaged values of maximal, linear cross correlation $h(EHG_1 \mid EHG_2)$.

and $h^2(EHG_1 \mid EHG_2)$ were statistically significant (p<0.001) but the difference between maximal values of linear cross correlations was statistically insignificant.

V. Conclusion

Contrary to well known electrocardiographical signals EHG signals do not have any characteristic shapes. It makes their analysis difficult. The goal of this paper was to use information contained in two components of an EHG signal for better description of uterine activities among pregnant women. Basing on a physiological model of a myometrium contraction we used a special index allowing for identification of nonlinear associations between two signals. The conducted analysis confirmed that during a pregnancy there was identified a nonlinear relationship between biopotentials generated by a fundus of an uterus and its cervix.

Biological data suggest that each myometric cell can be a source of bioelectrical potentials. Our results seem to support this hypothesis because the obtained cross-correlation sequences had similar bidirectional character.

Moreover, we confirmed the assumed hypothesis that the identified correlation ought to be stronger as a labour would be upcoming. This results suggest that information about this correlation may be used for prediction of an upcoming labour.

It is important to determine whether a value of the used index has stronger predictive power than hitherto proposed parameters basing on a single component of EHG signal. It requires further investigations on larger groups of pregnant women.

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