Effect of decimation on the classification rate of nonlinear analysis methods applied to uterine EMG signals

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Abstract - Recently, much attention has been paid to the use of nonlinear analysis techniques for the characterization of biological signals. Several measures have been proposed to detect nonlinear characteristics in time series. The effect of sampling frequency on the performance of these nonlinear methods has rarely been evaluated. In this paper we present a preliminary study of this effect for four methods that are widely used in nonlinearity detection: Time reversibility, Sample Entropy, Lyapunov Exponents and Delay Vector Variance. These methods have been applied to real uterine EMG signals in the aim of distinguishing between pregnancy and labor contractions. The signals were used to classify contraction before and after decimating them or (down sampling by a factor of 10). The results show that decimation improves the performance for sample entropy and reduces it considerably for Delay Vector Variance and only slightly for Time reversibility and Lyapunov exponents. Time reversibility still gives the highest classification rate. The methods were much less computationally expensive after down sampling.

Keywords
Nonlinear time series analysis, uterine electromyogram, effect of sampling frequency.

I. INTRODUCTION
Nonlinear time series analysis gives information about nonlinear features of biological signals, caused by the underlying nonlinear physiological mechanisms related to most biological systems. The uterus is a very poorly understood organ. It is deceptively simple in structure but its functioning is quite complex as it moves from pregnancy towards labor. This behavior, as observed by its electrical activity (electrohysterogram EHG), indicates that there are numbers of interconnected control systems involved (electric, hormonal, mechanical). When working together, they give rise to the nonlinear character observed in the EHG [1]. There is a growing literature reporting non linear biosignal analysis such as EEG [2], ECG [3], EMG [4] and EHG [5]. Several applications of nonlinear analysis methods have been done on the uterine EMG signals. We can cite here the comparison between Approximate Entropy, Correntropy and Time reversibility [5], the use of Sample Entropy [6] and the use of Detrended Fluctuation Analysis [3], as well as sensitivity and robustness analysis of four nonlinear methods [1]. In most of these studies the authors have reported some practical disadvantages of the methods i.e. impractically large calculation time for real time or immediate analysis. The study of the effect of decimation or down sampling on the performances of these methods, which is the main objective of this paper, is rare in the literature. In fact we have only found one example of this being done systematically and that is for [6].

Four methods: Time reversibility [7], Sample Entropy [8], Lyapunov Exponents [9] and Delay Vector Variance [10] were used in the this work. We tested the sensitivity of these methods to decimation on real EHG signals for the differentiation between pregnancy and labor contractions. This paper presents the comparison of methods with and without down sampling.

II. MATERIAL AND METHODS

A. Data
The methods used here are “monovariate” in that we used only one channel (bipolar vertical7: Vb7) from the 4×4 recording matrix located on the women’s abdomen. This channel is located on the median vertical axis of the uterus (see [11] for details). The signal was recorded on women in France and in Iceland. In Iceland we recorded signals on 22 women at the Landspitali University hospital, following a protocol approved by the relevant ethical committee (VSN02-0006-V2). In France we recorded signals on 27 women at the Center of Amiens for Obstetrics and Gynaecology, following a protocol approved by the local ethical committee (ID-RCB 2011-A00500-41). The sampling frequency of EHG signals was 200 Hz. They were segmented manually to extract segments containing contraction bursts. After segmentation we got 115 labor and 174 pregnancy EHG bursts that we used for the analysis below.

B. Methods

1. Time reversibility
A time series is said to be reversible only if its probabilistic properties are invariant with respect to time reversal. Time irreversibility (TR) can be taken as a strong signature of nonlinearity [12]. In this paper we used the simplest way, described as follow to compute time reversibility for a signal:
\[ Tr(\tau) = \left( \frac{1}{N-\tau} \right) \sum_{n=\tau+1}^{N} (S_n - S_{n-\tau})^3 \]

where \( N \) is the signal length and \( \tau \) is the time delay.

2. Sample Entropy

Sample Entropy (SampEn) is the negative natural logarithm of the conditional probability that a dataset of length \( N \), having repeated itself for \( m \) samples within a tolerance \( \tau \), will also repeat itself for \( m+\tau \) samples. Thus, a lower value of SampEn indicates more regularity in the time series and is based upon the examination of local unpredictability at \( 2 \) and \( 3 \) Hz. Here, \( m \) and \( \tau \) are parameters, there is a corresponding target, namely the next sample \( x_i \). A set \( \beta_i(m,\tau) \) is generated by grouping those DVs that are within a certain Euclidean distance (\( \tau \)) to DV \( X(k) \). This Euclidean distance will be varied in a manner standardized with respect to the distribution of pair wise distances between DVs. For a given embedding dimension \( m \), a measure of unpredictability \( \sigma^2 \) (target variance) is computed over all sets of \( \beta_i \).

The mean \( \mu_d \) and the standard deviation \( \sigma_d \) are computed over all pair wise Euclidean distances between DVs given by \( ||x(i) - x(j)|| \) (\( i \neq j \)). The sets \( \beta_i(m,\tau) \) are generated such that \( \beta_k \) = \{x(i)(\forall ||x(k) - x(j)|| \leq \tau \} \) i.e., sets which consist of all DVs that lie closer to \( X(k) \) than a certain distance \( \tau \), taken from the interval \([\mu_d-n_d,\sigma_d, \mu_d+n_d,\sigma_d] \) where \( n_d \) is a parameter controlling the span over which to perform DVV analysis. For every set \( \beta_i(m,\tau) \) the variance of corresponding targets \( \sigma^2(m,\tau) \) is computed. The average over the \( N \) sets \( \beta_i(m,\tau) \) is divided by the variance of the time series signal \( \sigma^2 \). \( \sigma^2 \) gives the inverse measure of predictability, namely target variance \( \sigma^2 \).

\[ \sigma^2 = \frac{1}{(1/N)} \sum_{k=1}^{N} \sigma^2_k \]

III. RESULTS

Our signals were recorded with a sampling frequency of to 200 Hz. The useful content of EHG is known to range between 0.2 and 3 Hz [15]. A high sampling frequency made the calculations more intensive, but on the other hand a low sampling frequency may negatively affect the results of the methods. For that we tested the nonlinear methods on signals with the original sampling frequency (200 Hz), and after decimation (20 Hz).

We investigated the effect of down sampling on the performances of pregnancy/labor classification. Our objective is to see if there is significant influence of down sampling on the results and if so if it is for the better or the worse. If the effect is small we will gain computational time without affecting the classification rate.

We plot the ROC curves for the 4 methods for the original sampling rate (200 Hz) in Fig. 1(a), and for the decimated signals (20 Hz) in Fig. 1(b). The area under the curve (AUC) for the ROC curves is presented in Table 1.
cases are not very different (Table 1). DVV is more affected than TR and LE and its already low discrimination becomes even worse. The performance of SampEn increases drastically after down sampling as its AUC goes from 0.478 to 0.672 (Table 1). The computation time for all methods decreases from 8.27 hours to 18 minutes after down sampling (Table 1).

I. DISCUSSIONS - CONCLUSIONS
This paper presents the results of a preliminary study of the effect of down sampling on four nonlinear methods (TR, SampEn, DVV, LE) applied to uterine EMG signals classification.

If we prove that down sampling do not induce noticeable effect on the classification rate of the methods, we can reduce the computational costs. To test this we down sampled our EHG signals from 200Hz to 20Hz.

<table>
<thead>
<tr>
<th>ROC curve parameter</th>
<th>AUC Fe=200 Hz</th>
<th>AUC Fe=20 Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>TR</td>
<td>0.842</td>
<td>0.809</td>
</tr>
<tr>
<td>DVV</td>
<td>0.615</td>
<td>0.541</td>
</tr>
<tr>
<td>SampEn</td>
<td>0.478</td>
<td>0.672</td>
</tr>
<tr>
<td>LE</td>
<td>0.738</td>
<td>0.731</td>
</tr>
<tr>
<td>Computational Time</td>
<td>8.27 h</td>
<td>18 min</td>
</tr>
</tbody>
</table>

TABLE 1: Comparison of ROC curve Area Under the Curve (AUC) for labor/pregnancy classification.

Methods are compared using ROC curve plots and the associated AUC. The main findings of the study are the following: by down sampling, (i) The performance of LE and TR, which were evidenced as the most powerful methods for labor/pregnancy classification in our previous study [1], are slightly reduced. AUC of TR decreases from 0.842 to 0.809, but this may be acceptable as a compromise the computation time saved; (ii) The performances of DVV method is reduced more than the TR and LE ; (iii) The performances of SampEn is, as expected, highly influenced by down sampling due to its dependence on signal point numbers and sampling as indicated in the name of the method. They are remarkably increased, but its AUC is still lower for TR which remains the best method for classification. We conclude that down sampling does not cause a significant damage to the classification rate of the methods and can be considered robust for the one fairly drastic down sampling that we performed in this limited preliminary study. The increase in the classification rate of SampEn shows that this method is much more sensitive to the sampling frequency of the signal and that to optimize the performances of the method the sampling frequency needs to be carefully chosen. Future work will tackle the question of the optimal sampling frequency for these methods in general and in particular for SampEn. Down sampling by a factor of 10 decreases the computational time by a factor of 27.5. This makes the clinical application of these methods much more realistic and help us to attempt to use these methods for the prediction of normal and preterm labor.

REFERENCE