Frequency Analysis of Fetal Heart Rate Signal

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***Abstract*— The analysis of a fetal HR (FHR) signal represents a non-invasive fundamental tool for the monitoring of fetal conditions in the antepartum period. In this work we apply both parametric and non-parametric methods for a PSD evaluation, in order to analyze the FHR signals of 5 healthy fetuses and 5 fetuses suffering for IUGR (IntraUterine Growth Restriction).**
An application of a non-linear algorithm, such as approximate entropy, is reported too. Our results are in agreement with previous works present in literature.

Index Terms — Autonomic Nervous System (ANS), Cardiotocography (CTG), Fetal Heart Rate (FHR), IUGR, nonlinear parameters, spectral analysis.

INTRODUCTION

Heart rate variability (HRV) is the physiological phenomenon of variation in the time interval between consecutive heartbeats. It is measured as the variation in the beat-to-beat interval.
Parameters extracted from HRV signal really differentiate pathological states, providing interesting hints about the generation of the disease conditions. These HRV properties could be particularly useful in monitoring the fetal wellbeing. Moreover, HRV analysis provide a quantitative tool for evaluating the synergetic control activity performed by the sympathetic and parasympathetic branches of the ANS.
Fetal electrocardiography (FECG), photoplethysmography (PPG), doppler ultrasound, ultrasound based cardiotocography (CTG) and fetal magnetocardiography (FMCG) are techniques applied daily in order to obtain the FHR signal. However, this paper will not discuss about their execution or performance.

I. MATERIAL AND METHODS

The analysis is performed on MATLAB, which is a desktop environment tuned for iterative analysis and design processes. The available data consists in two sets of 5 signals of similar length, sampled at 2Hz, referring to 5 healthy fetuses and 5 fetuses afterwards diagnosed with IntraUterine Growth Restriction (IUGR).
In the following paragraphs are reported the main steps of our work.

A. Loading Data

First, the 10 signals are imported and stored into two different cell arrays and are later plotted in order to perform an initial qualitative inspection. The RAW HRVs are represented in bpm units. After converting them into milliseconds, the outliers are removed replacing them with *NaNs* values. The values considered *outliers* are defined as the ones outside of the 5^{th}-95^{th} percentile range.

B. Preprocessing

Prior to the frequency domain analysis, different preprocessing steps are required. The baseline shift (which is due to artifacts) is then removed, then a truncation of the signal is performed, up to a number of samples multiple of the number of windows chosen (50). Finally, the signal is cleaned from *NaN* values using a spline interpolation. *Figure 1* reports an example of the complete pre-processing phase.

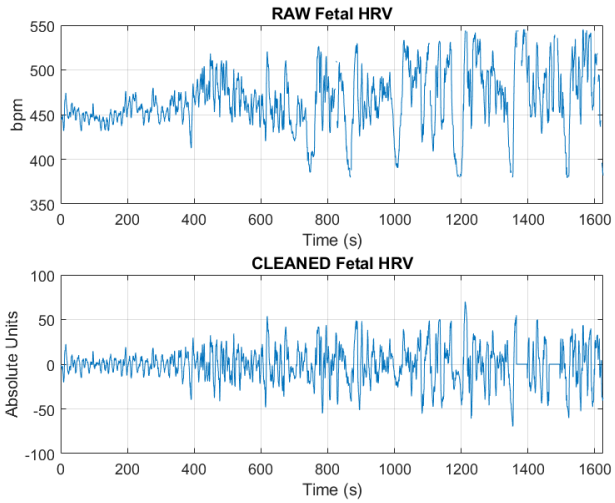

***Figure 1**: Signal prior and post the pre-processing steps.*

C. Spectral Analysis and Decomposition

After the preprocessing phase, this work proceeds to the frequency domain analysis. Using pre-implemented

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MATLAB functions, the Power Spectral Density (PSD) is calculated through non-parametric (Bartlett and Welch) and parametric (Yule-Walker) methods. The Welch method is performed using explicit Hamming windows and a 50% overlap; the order chosen for the Yule-Walker method is 20.
Then four frequency intervals are defined, which correspond to the Very Low Frequencies (VLF), Low Frequencies (LF), Medium Frequencies (MF) and High Frequencies (HF), and the corresponding areas under the curve are calculated through a trapezoidal integration.
The frequency ranges used are described in the following table.

Interval	Frequency Range
VLF	0 – 0.03 Hz
LF	0.03 – 0.15 Hz
MF	0.15 – 0.5 Hz
HF	0.5 - f_{Ny} *Hz*

Last, the Compressed Spectral Arrays (CSA) is computed calculating the PSD of each window.

D. Approximate Entropy

In order to extract regularity indexes, we calculate the approximate entropy (ApEn), which extracts non-linearities that aren't detected with the Fourier Transform. Results obtained by the algorithm we generate are saved into a *.mat* file.

II. Results and Discussion

The analysis previously described has been applied to the 5 healthy and 5 pathological fetuses. An example for each category is shown in *figure 2* and *figure 3* (see *Appendix)*, in which is reported the raw and clean signal, its PSD and the CSA.

In the PSD, the parametric and non-parametric methods show the peaks in the VLF, LF, and (if present) HF intervals. As we can see, in the time domain the two examples do not show any evident difference. Instead, the PSD highlights a mismatch in the magnitude of the peaks, especially in the LF. This is evident in *figure 4*. Some signals, also, present a small peak in the HF, near 0.7Hz. This value corresponds to the respiratory rate of the fetus.

In order to establish if the analysis in the frequency domain is able to distinguish the two categories of signals, the ratio between LF/(MF+HF) is calculated for each signal. The 10 ratios obtained are reported in the following table.

LF/(MF+HF) RATIO						Mean
Healthy	9.89	5.29	8.60	6.93	10.92	**8.33**
IUGR	3.52	1.81	9.21	5.80	4.95	**5.06**

Furthermore, the CSA plot allows to evaluate if the spectral components are maintained throughout the entire duration

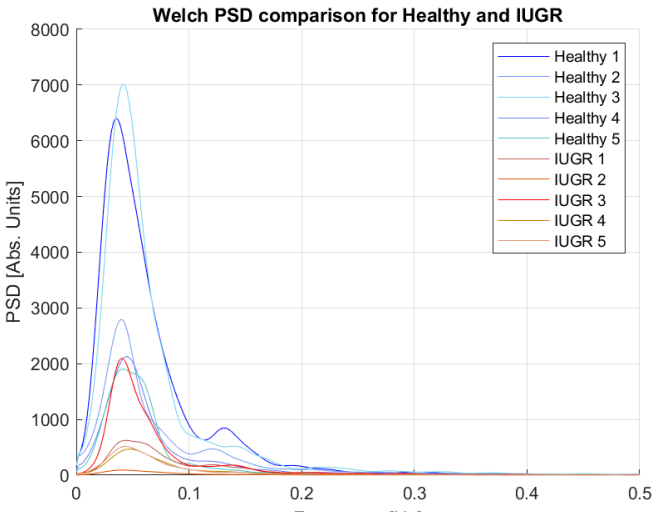


Figure 4: *PSD of the healthy (blues) and pathological (reds) signals. The frequency range shown spans from 0 to 0.5 Hz*

of the signal or if the HRV measurement is taken in a moment of transition between a *quiet* phase and an *activity* phase. The plot reported in *figure 5* shows, as a matter of facts, a few first windows where the peaks in the PSD are way less pronounced compared to the ones in the following windows. Windows from $k = 0$ to $k = 10$ are associated to a quiet phase, while windows from $k = 11$ to $k = 50$ correspond to an activity phase. The duration of the available signals is too short to highlight the presence of an entire phase, as a matter of fact the duration of either phases is at least 30 minutes.

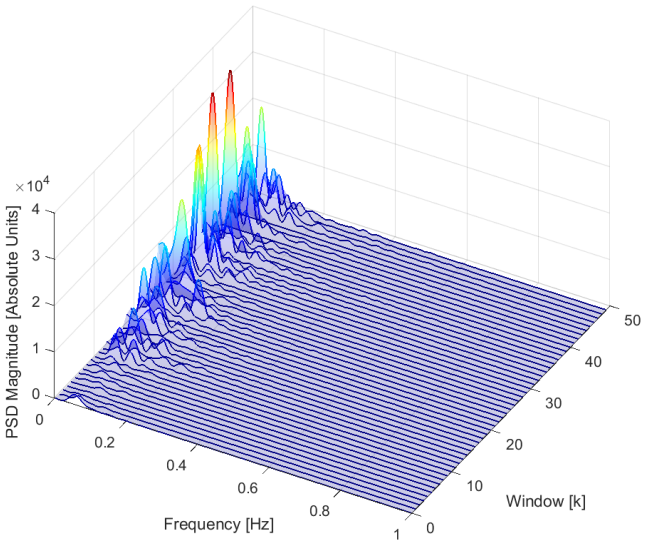
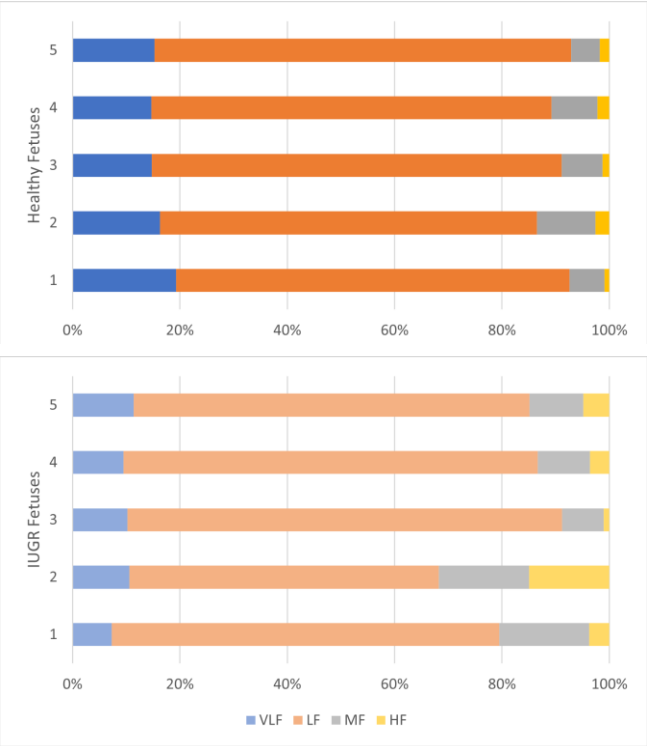


Figure 5: *CSA plot showing a transition between a Quiet phase and an Activity phase*

As regards the spectral decomposition of the signal, the results of the trapezoidal integration method are reported in the following normalized *barplots*, in order to correctly compare the variance distributions in the different frequency ranges.



Its clear how the signals referring to the IUGR cases are characterized by a relative lower variance in the VLF ranges and a higher variance in the MF and HF ones.

Calculating the approximate entropy ApEn of the signals didn't highlight any differences, with values stabilizing around 0.9 for both the healthy fetuses and the ones suffering from IUGR.

III. Conclusion

While the time-domain-based analysis does not underline all the differences between healthy and pathological FHRV signals, in the frequency domain is possible to emphasize the different features of the two categories. In terms of LF/(MF+HF), the healthy fetuses show a mean value higher with respect to the ones suffering form IUGR. Moreover, the power associated to the LF range is different between the two categories.

The assessment of ApEn is not useful to differentiate the two categories, but this result is highly dependent on the available signal length.

In conclusion, frequency domain analysis of FHRV allows to assess the well-being of fetuses in the antepartum period.

IV. Appendix

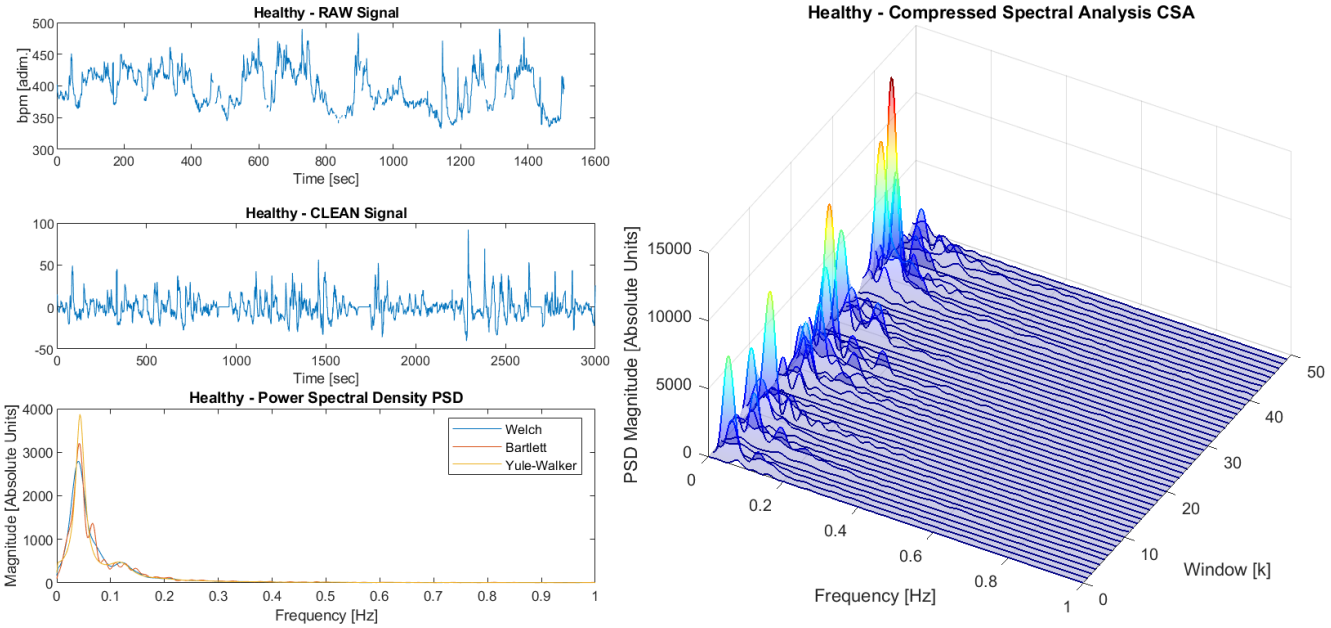


Figure 2: *Plots of the complete analysis of a FHRV from a healthy fetus.*

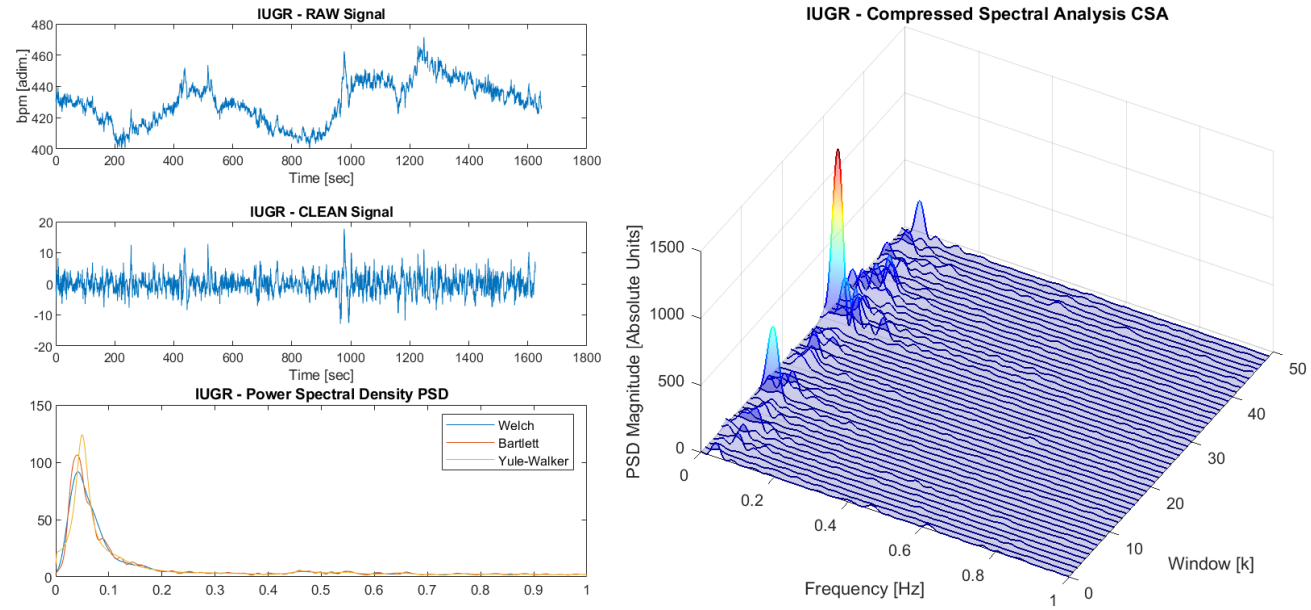


Figure 3: *Plots of the complete analysis of a FHRV from a fetus suffering from IUGR.*