Proceedings of the Technical Sessions, 39 (2023) 3-9
Institute of Physics, Sri Lanka

Analyzing Heart Rate Variability of Arrhythmia Patients Using Wavelet Transformation

T.G.S.V. Perera, N.G.S.S. Gamage*
Department of Physics, Faculty of Applied Sciences, University of Sri Jayewardenepura
Email: *sng@sjp.ac.lk

1. ABSTRACT

Analyzing heart rate variability (HRV) offers a possibility to understand the functioning of the autonomic nervous system (ANS). This is a noninvasive approach that can be used in clinical diagnostics. There are different methods to analyze HRV and the approach that was taken during this study is frequency domain analysis, specifically by using wavelet transform methods. Wavelet transform has advantages over Fourier transform due to its ability to perform multiresolution analysis. The wavelets can be scaled and translated into different levels throughout the signal that is being transformed and this results in transform coefficients with better resolution. The HRV spectrum falls within the 0.003-0.5Hz frequency range. This range can be further divided into four bands which are ultra-low frequency (ULF), very low frequency (VLF), low frequency (LF) and high frequency (HF). In previous studies, the LF/HF value has been used as a measure to determine the balance between the parasympathetic nervous system and the sympathetic nervous system. This study used the LF/HF ratio to find a connection between arrhythmia and HRV and it showed that arrhythmia patients have a lowered LF/HF ratio than that of healthy patients.

2. INTRODUCTION

The Autonomic Nervous System (ANS) is a primitive part of the nervous system. It consists of two components, the sympathetic nervous system, and the parasympathetic nervous system. The sympathetic nervous system (SNS) triggers the flight-or-fight response in the human body, it will prepare the body for a stressful situation. In contrast the parasympathetic nervous system (PNS) triggers the relaxation response. This is related to controlling bodily functions, it calms nerves to return to regular function.

The variation in time between two consecutive heartbeats is known as HRV, usually, this is measured in milliseconds. This variation is controlled by the ANS. When the SNS is dominating, that is when the flight-or-fight response is in charge, the heart rate increases leaving a small space between heartbeats, which will result in low variability in the heart rate. In other words when the flight-or-fight response is activated HRV will decrease. In contrary, when the PNS is activated the heart rate will decrease, which gives more space between heartbeats and allows great variations. This means when PNS is dominating the HRV will increase.

Previous studies suggests that HRV can be used as a biomarker to identify diseases. Blood pressure fluctuations, recent myocardial infarctions, diabetes and panic disorder are some of them which tend to decrease the HRV [1]–[5] habits such as consuming alcohol and smoking also tends to decrease HRV [6], [7]. Other factors such as age and gender has also been found to have a correlation with HRV [8], [9].

There are a few types of analysis methods that can be used in analyzing HRV.

1. Time domain analysis
2. Non-linear methods of analysis
3. Frequency domain analysis

In this study we were only focused on the frequency domain analysis methods. The most common frequency analysis technique is Fourier Transforms (FT). However, using FT methods has its limitations on non-stationary signals such as Electrocardiograms (ECG) that were used during this study. When transforming bio signals to frequency domain time information tends to be lost or have restricted resolution. Since HRV is a complex non-stationary signal having these inaccuracies would make a great effect on the observed results. Therefore, this study was conducted using Wavelet Transform (WT) methods which is much more compatible with non-stationary signals.

2.1 Wavelet Transformation

A French geophysical engineer Jean Morlet first introduced the concept of using a Mother Wavelet to create a family of sub functions. The mother wavelet ϕ(t) is defined as follows.

$$\varphi_{a,b}(\mathrm{t}) = \frac{1}{\sqrt{|a|}}\varphi\left(\frac{t-b}{a}\right),\ \ a, b \in \mathbb{R}, a \neq 0 \qquad \text{Equation (1)}$$

Here ***a*** is known as the "scaling" parameter, which decides the degree of compression or scale, and ***b*** is known as the translation parameter which determines the time location of the wavelet. These wavelets have time widths adapted to their frequencies which is the main reason for the success of the wavelets in signal processing and time–frequency signal analysis.

The wavelet should be chosen according to the signal that is being processed. As our only concern is analyzing the heart rate, choosing a wavelet that looks similar to an ECG waveform would be ideal. Some examples of such wavelets are the Daubechies family and the Symlet family[10].

There are two main forms of WT that can be used in frequency analysis, that is Discrete Wavelet Transformation (DWT) and Continuous Wavelet Transformation (CWT). DWT uses discrete values for ***a*** and ***b*** and therefore it is more computationally modest than CWT.

The HRV spectrum falls within the 0.003-0.5Hz frequency range and it further divides to four major frequency bands. Ultra-low frequency (LF), very low frequency (VLF), low frequency (LF) and high frequency (HF). The values for these frequency band indices were noted to differ in various studies. This is in relation to changes in the heart's autonomic modulations [11]. The vagus nerves are the main nerves related to parasympathetic activity and the vagal activity is a major contributor to the HF component. There is some controversy over the LF component. Some studies say that it is a marker for sympathetic activity [12]–[14], while some other studies state it includes both sympathetic and vagal activity (activity related to vagus nerves) [15], [16]. However, the LF to HF ratio (LF/HF) has been considered to represent the sympatho-vagal balance [11]. Nevertheless, there are few recent studies contradicting to this popular opinion [17].

However, the LF/HF ratio was taken into consideration during this study to find a connection between HRV and the sympatho-vagal balance in Arrhythmia patients.

3. METHODOLOGY

For this study two sets of data were required to make a comparison which were taken from an online database, “PhysioNet.org” which consists of real-life biomedical signals. From this database “MIT-BIH Arrhythmia Dataset” and “MIT-BIH Normal Sinus Rhythm Dataset” were used. Nine recordings were taken from the Arrhythmia dataset which were digitized at 360 samples per second per channel with 11-bit resolution over a 10 mV range, and six recordings were taken from the Normal Sinus Rhythm dataset which had a sample rate of 128Hz.

The .mat file formats were extracted from the database and then the signals were first plotted against time to visualize the ECG signals. For more accuracy these plots were compared with the plots available in the database, which were annotated by two or more cardiologists[18].

The QRS complex of each heartbeat had to be located in order to calculate the HRV. This was achieved by using Maximum Overlap Discrete Wavelet Transformation (MODWT) as a technique to find R peaks. Both Daubechies and Symlet wavelets were used for this. After locating the R peaks the difference between two consecutive R peaks were measured in milliseconds and was plotted against time to visualize the variations. A visualization of the above process is shown in Figure 1.

After obtaining a function of HRV next step was to analyze the frequency components in it. For this CWT was applied to the HRV function. The spectrogram was observed, and the frequency bands were identified. To extract these three bands separately inverse continuous wavelet transform (ICWT) was applied three times on the frequency domain signal of the HRV function which was received by applying CWT. As a default, the VLF band was taken within [0.003-0.04] Hz, LF taken within [0.04-0.15] Hz and HF within [0.15-0.5] Hz. But by observing the spectrogram it was clear that for some signals the frequency bands deviated from these values. Therefore, the frequency bands were taken by observing the spectrogram of each signal. Figure 2 shows an example for choosing frequency bands according to the plotted spectrogram.

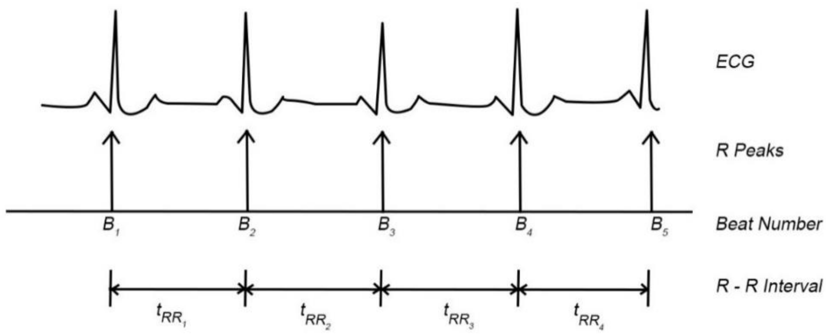

Figure 1: A visualization of how R peaks and RR intervals are calculated for the study.

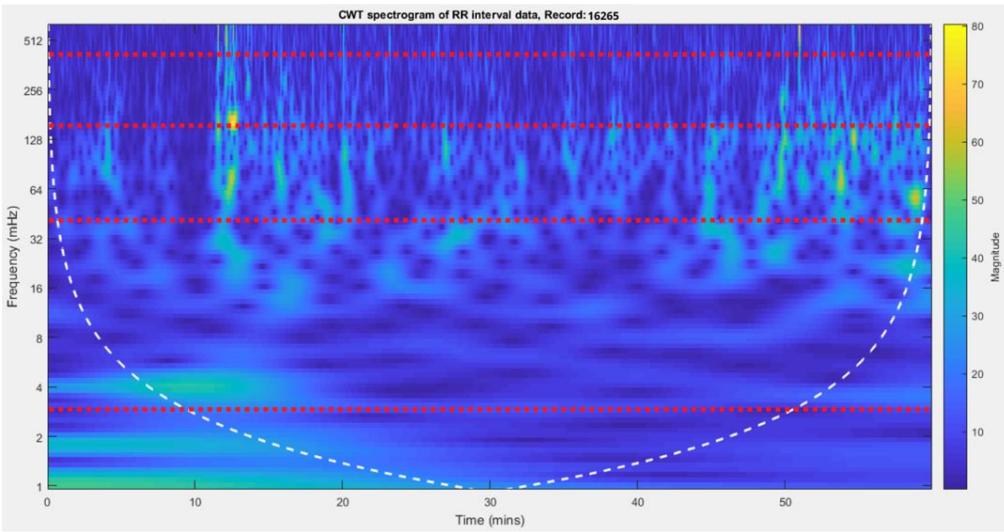

Figure 2: CWT spectrogram and chosen frequency bands for frequency extractions.

The final step was to calculate the power of these frequency ranges to get an idea about the contribution of each of the frequency bands to the original ECG signal. The square of the root mean square value of each of the functions were calculated. The values were normalized before using for analysis. Finally, the LF/HF ratio was computed by taking the ratios between the normalized power of LF and HF.

4. RESULTS AND DISCUSSION

The LF and HF bands are one of the main interests during this study in order to find a correlation between HRV and autonomic nervous system activity. In Figure 3 the LF/HF ratio value comparison is done for both datasets. Since the normal sinus rhythm dataset included data from people who were not identified with any present arrhythmia issues or other diagnosed diseases, it was assumed that these patients were comparatively healthier than the patients who were in the arrhythmia dataset. However, we need to keep in mind that any patient can be suffering from an undiagnosed disease that they were not aware of when the ECG signals were collected.

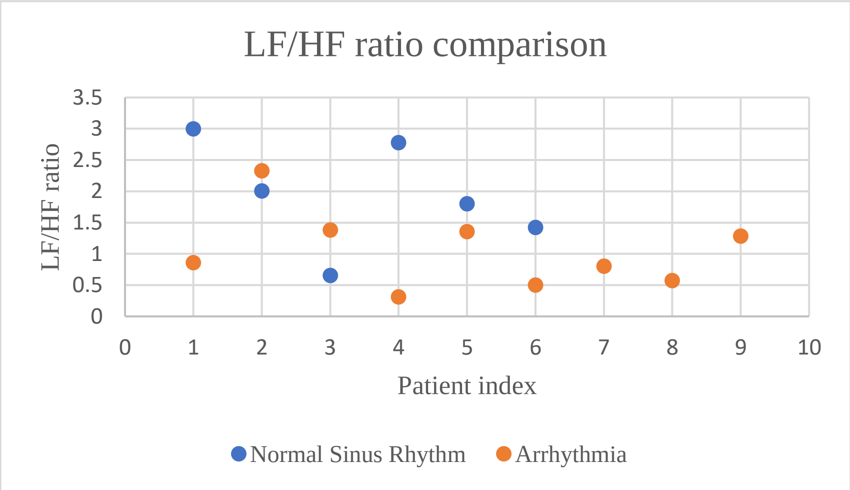

Figure 3: Scatter plots of LF/HF values for both datasets

According to the scatter plot shown in Figure 3 one thing that stands out is that the LF/HF ratio seems to be comparatively lowered for patients with arrhythmia with respect to healthy subjects. Five out of nine records had LF/HF values less than 1. This points to the fact that for these records the HF band was more powerful than the LF band.

An arrhythmia is a condition in which the heart beats with an irregular or abnormal rhythm. This means the heartbeats are going to be abnormal, which leads to irregular RR intervals causing higher variability in the heart rate.

The arrhythmia dataset has a lower LF/HF value overall. This points to the fact that arrhythmia might cause a lowered LF/HF value. This raises the next question of whether the LF/HF ratio also reflects the sympatho-vagal balance. The reason for stating that is because if it reflects the sympatho-vagal balance these values indicate that the parasympathetic nervous system (PNS) is dominating the autonomic nervous system (ANS) in a patient with arrhythmia. However, it is hard to believe that a person whose cardiac system is malfunctioning could have the PNS dominating the ANS causing the body to focus more on bodily functions while it is also undergoing a stressful situation. This suggests that for arrhythmia patients the HRV is higher than expected, which will result in a lowered LF/HF ratio. Therefore, for arrhythmia patients using LF/HF ratio as a parameter to judge the symapatho-vagal balance might result in inaccurate deductions.

5. CONCLUSION

During this study different versions of wavelet transform were used in different steps of the study to understand and test the performance of wavelet transform in this task. The use of MODWT as a form of discrete wavelet transform to localize R peaks showed satisfactory results. For the Normal Sinus Rhythm dataset, the LF/HF ratio was comparatively higher than that of the Arrhythmia dataset. The arrhythmia dataset had very low LF/HF values which rose the question of whether the LF/HF value could measure the symaptho-vagal balance as it has been mentioned in previous literature. This contradicting result led to the conclusion that for arrhythmia patients the LF/HF value might not be a suitable parameter to understand the activity of the ANS.

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