

A Declared Concept and a Proposed Algorithm to Assess HRV for Heart Disease Diagnosis

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Abstract: Nowadays, Variability of Heart Rate (HRV) becomes utmost important tool for predicting and diagnosing most of diseases. It depends on the diversity of heart complex wave. As heart complex wave is non-linear wave, therefore HRV is stochastic and chaotic (stochaotic) signal. HRV needs a very sensitive tool for analysing and predicting its variability. In previous era, Rosenstein (R) and Wolf (W) had used the Lyapunov exponent (LE) as a quantitative measure for HRV detection sensitivity, but the Rosenstein and Wolf methods diverge in determining the main features of HRV sensitivity, while Mazhar-Eslam introduce a modified algorithm to overcome the Rosenstein and Wolf drawbacks. Mazhar-Eslam Variability Frequency (MVF) used as quantitative and qualitative measure for HRV detection sensitivity.

The present work introduces a novel reliable method to analyze the linear and nonlinear behaviour of heart complex wave variability, and to assess the use of the HRV as a versatile tool for heart disease diagnosis. This paper introduces a declaration for the concept of the LE parameters to be used for HRV diagnosis and proposes a modified algorithm for a more sensitive parameters computation.

Keywords: Lyapunov exponent (LE), stochastic, Heart Rate Variability (HRV), Variability Frequency

I. INTRODUCTION

Variability of the Heart Rate (HRV) act as a universal measurement which used for analyzing heart activity. All actions and reactions effect and affect by the heart. Therefore, HRV analysis indicates reflection on the body status. Different pattern can describe the fluctuations in HR such as (linear, non-linear pattern), which classified into periodical and aperiodical oscillation. These patterns can be quantified in time domain using statistical analysis, in order to estimation the RR- fluctuations intervals.

The spectrum of HRV analysis shows HR band frequency variations. Which classified into three pattern: High, low and very low frequency band which vary from (0.15-0.5) Hz, (0.05-0.14) Hz, and (0.01-0.04) respectively. The higher band represent vagal modulation fragment indicator, and the lowerst one indicates an overwhelmingly sympathetic tone and baroreflex activity [1, 2, 3]. There are many research studied the linearity of HRV [4], But, it failed in full quantification the dynamic structure of the HR signals in order to extraction a highly sensitive diagnostic method for HR diseases.

In this work we introduces an insight about the most reliable method to analyze the linear and nonlinear behaviour of heart complex wave variability, Also assess the use of the HRV as a versatile measurement for heart disease diagnosis. This novelty introduces new algorithm called Mazhar-Eslam algorithm which considering whole cases of linear and nonlinear behaviour of the HRV signal and pattern.

II. DECLARATION OF PARAMETERS

Careful study of equation (1) identifies that the definition of Λ in [10, 11] as an exponent is far from fact, since it has dimension of time reciprocal, i.e. it represents some sort of repetition frequency in periodic and aperiodic signals. Also, in the case of chaotic attractors, it represents variations among the attractors.

$$\Lambda = \lim_{\substack{t \rightarrow \infty \\ |\Delta x_0| \rightarrow 0}} \frac{1}{t} \ln \frac{\Delta x(X_0, t)}{|\Delta x_0|} \quad (1)$$

Considering the physiological, psychological, and environmental stochastic-chaotic (stochaotic) nature of variability in HRs, the mentioned above repetition frequency must be defined as variability frequency (VF) in HRs, which is to be expressed as

$$\Omega_M = \lim_{\substack{t \rightarrow \infty \\ |\Delta x_0| \rightarrow 0}} \frac{1}{t} \ln \frac{\Delta x(X_0, t)}{|\Delta x_0|} \quad (\text{Hz}) \quad (2)$$

Where Ω_M (Hz) is Mazhar-Eslam Variability Frequency (MVF) in HRs of patient complex waves. To discriminate a mong heart stochaotic signals, the MVF must be used. The path of stochaotic signals in state-space follow typical patterns. Closely spaced trajectories converge and diverge exponentially, relative to each other. An exponential divergence of initially nearby trajectories in state-space coupled with folding of trajectories, to ensure that the solutions will remain finite, is the general mechanism for generating deterministic randomness and unpredictability. Therefore, the existence of a positive Mazhar-Eslam Variability Frequency

MVF (Ω_M) for almost all SED initial conditions in a bounded dynamical system is to be used as a definition of deterministic stochastic.

Take a case of two identical simple harmonic oscillators with different amplitudes. Because the frequency is independent of amplitude, a phase portrait of the two oscillators would be a pair of concentric circles. The orbits in this situation would maintain a constant separation. Finally, a positive MVF ($\Omega_M > 0$) implies the orbits are on a stochastic attractor. Nearby points, no matter how close, will diverge to any arbitrary separation. These points are unstable [7].

A negative MVF ($\Omega_M < 0$) means that the orbit attracts to a stable fixed point or stable periodic orbit. Negative MVFs ($\Omega_M < 0$) are characteristic of dissipative or non-conservative systems. Such systems exhibit asymptotic stability. The more negative the MVF, the greater the stability. Super stable fixed points and super stable periodic points have a MVF tends to infinity ($\Omega_M \rightarrow -\infty$). This is something similar to a critically damped oscillator in that the system heads towards its equilibrium point as quickly as possible.

Also, a zero MVF ($\Omega_M = 0$) means that the orbit is a neutral fixed point (or an eventually fixed point). An MVF of zero value indicates that the system is in some sort of steady state mode. A physical system with zero MVF is conservative. Such systems exhibit stability.

III. DISCUSSION

The introduced MVF " Ω_M " divergence of initially SED nearby trajectories in state-space is coupled with folding of trajectories. To discriminate between stochastic dynamics, periodic, and aperiodic signals, the MVF " Ω_M " are often to be used as a qualitative measure of SED. The trajectories of stochastic signals in state-space follow typical patterns. Closely spaced trajectories converge and diverge exponentially, relative to each other. Therefore, the existence of a positive MVF ($\Omega_M > 0$) for almost all initial conditions in a bounded dynamical system is to be used for the deterministic stochastic HRV cases.

Table 1 shows the spectrum bands of the normal HRV and some cases from MIT-BIH database, using the three algorithms: Mazhar-Eslam, Wolf, and Rosenstein, used to compare the SED precision of the three algorithms in determining the MVF.

It is worth to note that the introduced Mazhar-Eslam algorithm spectral analysis of the given HRV reveals three distinct frequency bands in the modulation of humans HRs. The first band is very low frequency (VLF) band in the range (0.01-0.05 Hz), the second band is low frequency (LF) band in the range (0.06-0.15 Hz) and the third band is a high frequency (HF) band in the range (0.16-0.50 Hz) as illustrated in (**Fig 2**). These results coincides with that mentioned in [8].



Figure 2 The introduced MVF spectrum bands of HRVs.

The new measure is high frequency error is calculated as

$$HF \text{ error } (r_H = \frac{HF}{total}) \tag{3}$$

Therefore, the high frequency error r_H for MVF algorithms shown in **table (1)** are

$$\text{Rosenstein } r_{Hr} = \frac{22}{22} \times 100\% = 100\%$$

$$\text{Wolf } r_{Hw} = \frac{12}{22} \times 100\% = 54.54\%$$

$$\text{Mazhar-Eslam } r_{Hm} = \frac{0}{23} \times 100\% = 0\%$$

The **figure 3** shows the bar diagram of high frequency error

Table 1 The MVF results of different methods using normal case and MIT-BIH sample cases.

Parameter		MVF		
Serial	Method	Rosenstein	Wolf	Mazhar-Eslam
	Case			
1	Normal	0.7586 (HF)	0.505 (HF)	0.4986 (HF)
2	101	0.2500 (HF)	0.1700 (HF)	0.0830 (LF)
3	102	0.1600 (HF)	0.1300 (LF)	0.0530 (VLF)
4	104	0.2100 (HF)	0.1300 (LF)	0.0700 (LF)
5	106	0.2300 (HF)	0.1500 (LF)	0.0770 (LF)
6	107	0.2000 (HF)	0.1300 (LF)	0.0667 (LF)
7	109	0.2200 (HF)	0.1400 (LF)	0.0733 (LF)
8	111	0.2400 (HF)	0.1600 (HF)	0.0800 (LF)
9	112	0.2400 (HF)	0.1700 (HF)	0.0800 (LF)
10	115	0.2800 (HF)	0.1700 (HF)	0.0930 (LF)
11	117	0.2300 (HF)	0.1600 (HF)	0.0770 (LF)
12	118	0.2500 (HF)	0.1600 (HF)	0.0833 (LF)
13	119	0.2700 (HF)	0.1700 (HF)	0.0900 (LF)
14	121	0.2500 (HF)	0.1600 (HF)	0.0840 (LF)
15	122	0.2300 (HF)	0.1600 (HF)	0.0770 (LF)
16	123	0.2300 (HF)	0.1500 (LF)	0.0770 (LF)
17	124	0.2500 (HF)	0.1700 (HF)	0.0840 (LF)
18	200	0.2300 (HF)	0.1500 (LF)	0.0770 (LF)
19	203	0.2300 (HF)	0.1500 (LF)	0.0770 (LF)
20	212	0.2100 (HF)	0.1400 (LF)	0.0700 (LF)
21	221	0.2100 (HF)	0.1400 (LF)	0.0700 (LF)
22	230	0.2100 (HF)	0.1400 (LF)	0.0700 (LF)
23	231	0.2200 (HF)	0.1500 (LF)	0.0740 (LF)

* HF high frequency, LF low frequency, and VLF very low frequency.

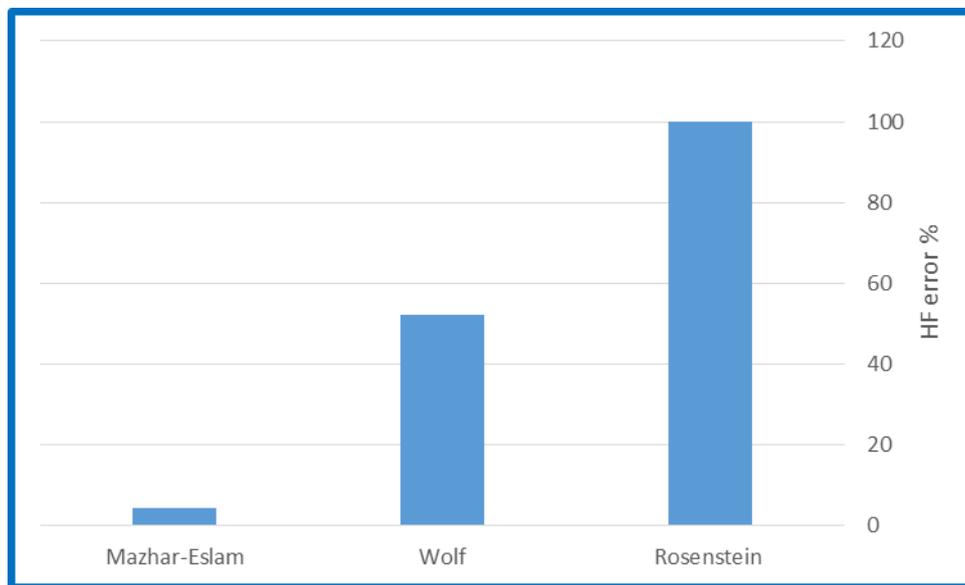


Figure 3 High frequency error.

By reference to MIT-BIH arrhythmia database medical records, it is found that the cases in **table 1** are critical cases as shown in **(Fig. 5)**. Some cases have Ventricular ectopy like 102, 104, 106, 107, 109, 119, 123, 221, and 231 as seen in **(Fig.6)**, and some of these cases have Supraventricular ectopy like 111, 112. In addition, some of these cases in **table 1** have both Supraventricular ectopy and Ventricular ectopy like 118, 124, 200, and 203. The Ventricular ectopy and Supraventricular ectopy lie in HRV low frequency band, because of their MVF

is low. **Table 1** shows that the Mazhar-Eslam algorithm for MVF $\overline{\Omega_M}$ is more precise than Wolf and Rosenstein algorithms. Also, the Mazhar-Eslam algorithm shows that the selected cases from MIT-BIH are in the low frequency range as its spectrum variation indicate ($\Omega_M < 0.16$ Hz). The Wolf algorithm has less precision than Mazhar-Eslam algorithm. Wolf observed incorrect band for cases 111, 112, 115, 117, 118, 119, 121, 122, 124, and 231 because they are not in the high frequency band as it shows but they are in the low frequency band as mentioned before. The worst and imprecise algorithm is Rosenstein as it shows all cases in the high frequency band. Thus, the Mazhar-Eslam is a recommended algorithm for HRV analysis.

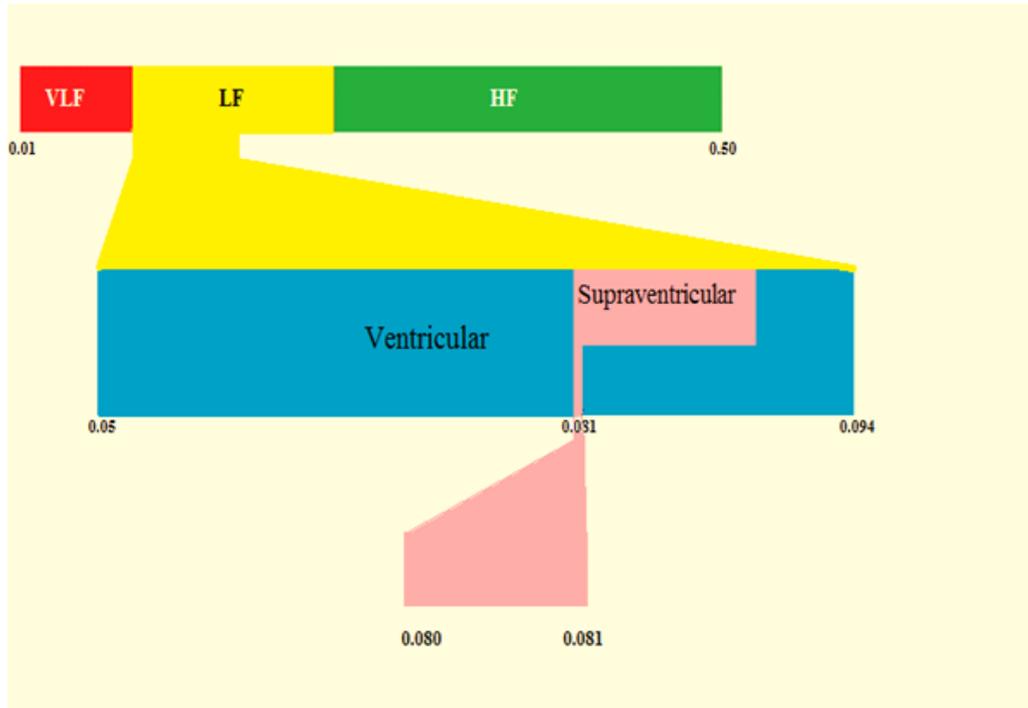


Figure 4 The MVF diagnosis diagram for ventricular and supraventricular

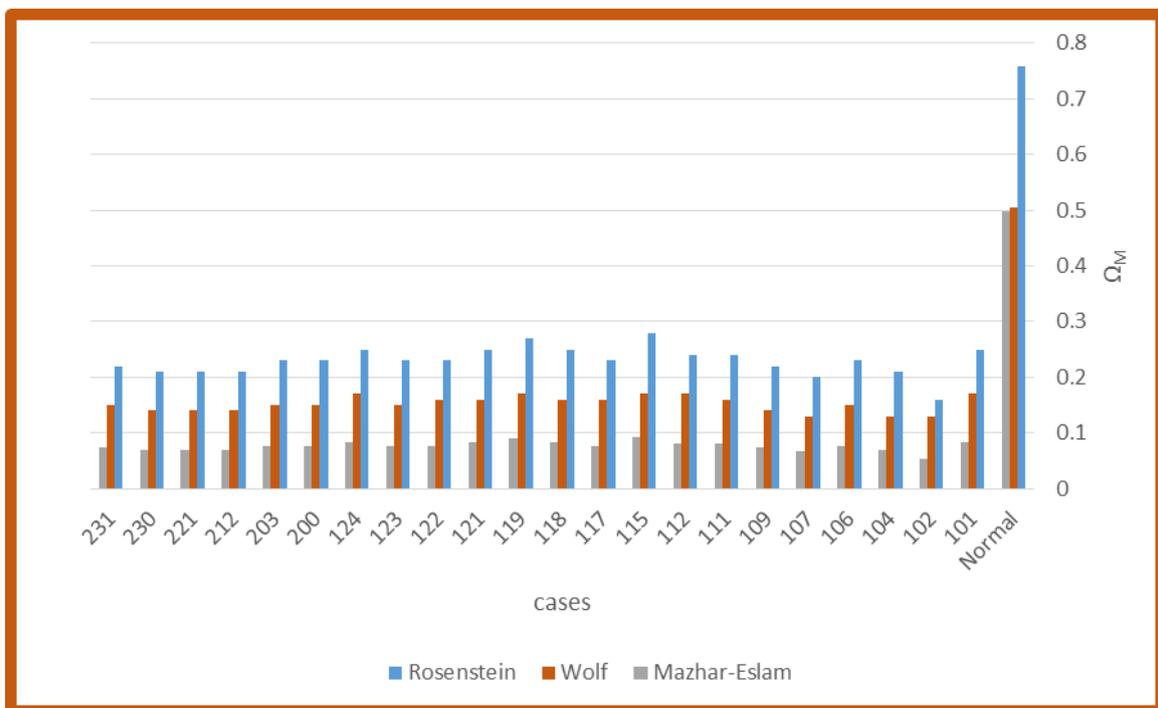


Figure 5 The MVF of the given cases.

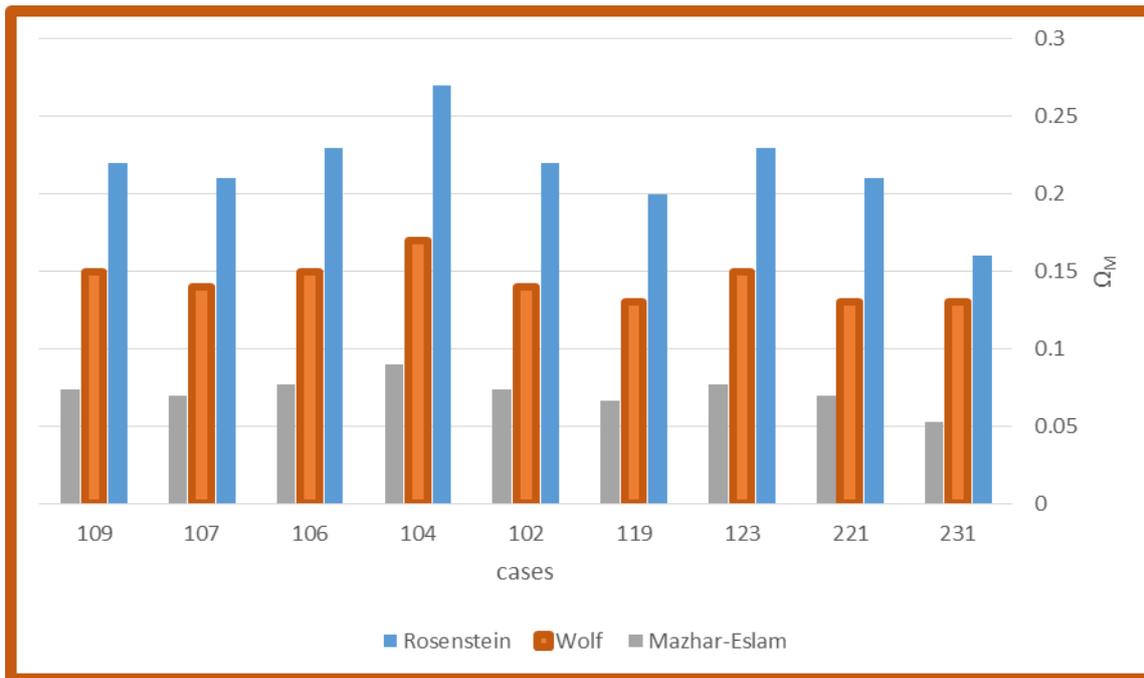


Figure 6 MVF ventricular cases

IV. CONCLUSION

Heart Rate Variability (HRV) is reported in several cardiological and non-cardiological diseases. Also, it has a prognostic value and is therefore very important in modelling the cardiac risk. HRV is stochastic signal that remains highly controversial. In order to have utmost importance, HRV needs a sensitive measure to analyse it. It is concluded that Mazhar-Eslam variability mean frequency (MVF), is a versatile and more precise qualitative SD measure of HRV sensitivity than others. The Rosenstein algorithm provided less sensitive *MVF* estimates than the Wolf algorithm to capture differences in local dynamic stability from small gait data sets. The data supported the idea that this latter outcome results from the ability and inability of the Wolf algorithm and Rosenstein algorithm, respectively, to estimate adequately MVF of attractors with an important rate of convergence as those in gait. Therefore, the Mazhar-Eslam algorithm appears to be more qualitative and appropriate to evaluate local dynamic stability from small gait data (SD) sets like HRV. Increase in the size of data set has been shown to make the results of the Mazhar-Eslam algorithm more suitable, although other means as increasing the sample size might have a similar effect. The Mazhar-Eslam algorithm uses the merits of the Discrete Wavelet Transform (DWT) instead of Fast Fourier Transform (FFT) unlike Rosenstein and Wolf. The Mazhar-Eslam algorithm cares for all SD variants especially the small ones like that are in HRV. These SD variants may contain many important data to diagnose diseases as R-R interval has many SD variants. Thus, the Mazhar-Eslam algorithm for MVF ($\overline{\Omega_M}$) taking determination all of Ω_M s is characterized by its high SD robustness, and precise qualitative predictor. The Mazhar-Eslam algorithm presents a new chapter for HRV diseases diagnosis. It contains a positive part for HRV as it is stochastic signal.

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