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Measurement of Heart Rate by Chaotic System Prediction

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ABSTRACT

In this paper we introduce deterministic chaos a new field of study that has started changing the ideas and the ways of looking at statistics results it attracts the attention of many scientists like pure and applied Mathematics, then we introduce The physiological phenomenon of fluctuation in the space between heartbeats is known as heart rate variability. It is determined by the variability in heart rate variability parameters, which provide details on the cardiovascular system's complexity or scaling behavior. Using the chaos theory framework, the purpose of this study was to investigate how gender, age, and day/night variation affected these characteristics of nonlinear heart rate variability, which examines the behavior of dynamical systems that are highly sensitive to beginning conditions. While nonlinear heart rate variations decrease with age, they were shown to be more prevalent at night.

1. Introduction

The study of non-linear "dynamical systems" and the behavior of dynamical systems whose behavior is very sensitive to beginning conditions are covered by the essential mathematical theory of chaos. Numerous mathematicians and scientists contributed to the development of the "chaos theory", and it has applications in a wide range of scientific disciplines. Chaos theory has applications in plenty of areas, like meteorology politics, population dynamics, psychology, robotics, climatology, animal population dynamics, structural engineering, Computer science, economics, finance philosophy, physics, programming, microbiology, biology, vibrations, and so on [1]. According to what has been said chaos studies can help researchers to find a new way of answering their unsolved questions. One of the applications of chaos is in biology. As medical researchers showed in the meaning of chaos is a state of disorder. Chaos theory has a clearer description rather than just its meaning [2]. When a dynamical system possesses any one of the following three characteristics, it is said to be chaotic [3]:

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1. Being sensitive to initial conditions.
2. Topologically mixing is present.
3. Having dense periodic orbits.

The study of complicated nonlinear dynamical systems is what makes chaos theory one of the essential theories in our daily lives. Systems are the focus of this area of mathematics. Understanding chaos theory will help make a complicated system more predictable. Edward Lorenz brought the phenomenon to the modern world in 1977 with the idea of the Butterfly Effect [3].

Cardiovascular structure and autonomic cardiovascular regulation differ during the day and night, and functions vary with age, increasing the risk of developing "cardiovascular disease". Even so, it is still unclear what precise processes underlie this circadian profile of harmful vascular events. In this paper, we introduce one of the important applications of chaos theory in biomedical. Many implied systems have a function that exponentially decays with time, however when the system is in the human body, then such exponential decay will not happen, in other words, a single characteristic time cannot be a good indicator of the behavior of that system. Instead, power law Functions are good correlations for these complex systems [4].

2. Chaotic system

Since chaotic systems frequently react in important ways rather than resisting outside shocks, they are unstable. In other words, they don't only ignore outside influences; they also use them to their advantage. Due to their small number of components, these systems are deterministic make no mention of implicit random processes, and only use simple differential equations [4]. A system is said to be chaotic whenever its evolution depends on the original conditions when there is no randomness involved in the generation of future states of the system. This feature implies that two paths arise from two distinct, nearby initial conditions, but experimental observations have only confirmed this in the last thirty years of the twentieth century. chaotically described as being. They can be discovered in astronomy, the solar system, the brain and heart of living things, and many other fields [4].

3. Application of chaos theory in our life

Chaos theory can be applied in many scientific disciplines, One of the successful uses of chaos theory is in ecology, where it demonstrates how growth is density-dependent and can result in chaotic dynamics. In the setting of chaotic systems, quantum chaos theory explains how the relationship between quantum physics and classical mechanics functions. Recent research has been done on a different field called relativistic chaos that abides by the general relativity principles [5]. There is a fast-emerging new area named nonlinear signal processing and communications with reliable results. Scientists would not appreciate this area so far. However, studying the history of interaction between signal processing and statistics can be good proof that suggests researchers do not miss the new methods of study. The following are some significant ways that chaos theory is used in daily life [6]:

1. Chaos theory in the stock market.

2. Fashion design and chaos theory in the textile industry.

2. Chaos theory in the human body.
3. Chaos in the social sciences.
4. Chaos in Engineering.
5. Chaos in Circuits
6. Chaos in producing music.
7.

4. Linear, Nonlinear systems

Most of our learning about physiological systems has been achieved by using linear system theory. Many biomedical signals are random or aperiodic in time. Simple Mathematical models for analyzing and controlling physiological systems can be achieved. According to the research done by physiology, the cardio system behavior is obeying nonlinear dynamics [7]. To better comprehend the processes in cardiac systems, it is crucial to describe linearity and nonlinearity. When the system is linear the output will be controlled by the input with simple linear equations like:

$$D = nx + b \quad \dots\dots\dots\dots (1)$$

A simple linear well-known system is "ohm aw".
A system can be

$$y = ax(1-x) \quad \dots\dots\dots\dots (2)$$

Which is named the "logistic equation" in population biology. The nonlinearity of this system is because of (x^2) Depending on the value of a regular oscillation, steady states or highly erratic behavior can be generated.

5. The concept or notion of time series in Heartbeats

There are some important aspects of nonlinear dynamics, with an emphasis on heartbeat control will be discussed. In nature, many simple systems have a function that exponentially decays with time, however, when the system becomes more complex, like for example the cardiovascular system in the human body, then such exponential decay will not happen other words single characteristic time cannot be a good indicator of the behavior of the system [5]. Heartbeat sequences are an area of study that has become interesting in recent years. The heartbeat of several people was recorded in 24-hour intervals in their primary experiments which were represented by time series from sequential intervals from beat $(x+1)$ showed by $Z(x)$, The mean variation function $T(x)$ was introduced as follows:

$$T(x) = ID(x^2 + x) - D(x)I \quad \dots\dots\dots\dots\dots (3)$$

In equation (1), $T(x)$shows the variation over different values of (x), and the values of (x) will be the average value of all (xs). When the plot of $T(x)$ vs. x was drawn the relationship was described in the following equation:

$$T(x) \sim x^{\alpha} \quad \dots\dots\dots\dots (4)$$

Which exponent α, was near 0 for healthy and nearly 0.5 for diseased samples.
After a while a new stochastic variable of $I(x)$ named the time beat intervals was introduced:

$$I(x) \equiv D(x+1) - D(x) \quad \dots\dots\dots\dots\dots (5)$$

With this variable, power spectra analysis could be done because $I(x)$ is more fixed. This analysis result in:

$$S_I(T) \sim \frac{1}{T^{\beta}} \quad \dots\dots\dots\dots (6)$$

6. Measurement of Heart Rate Variability (HRV) parameters

Although measurement (HRV) can explain the scale and complexity characteristics of the signal, it cannot indicate the amount of modulation as such. Time series for any heartbeats $Qn.n = 1.2.\dots.N$ It is suggested to use a closed-loop version of the dynamics, where the output Qn returns as a postponed input. Utilizing a discrete Volterra autoregressive series of degrees, the univariate time series are investigated. (d) and memory (z) to calculate the anticipated time series using a model:

$$\begin{aligned} Qn^{adc} = a_0 + a_1 Q_{n-1} + a_2 Q_{n-2} + \cdots + a_z Q_{n-z} \\ + a_{z+1} Q_{n-1}^2 + a_{z+2} Q_{n-1} Q_{n-2} + \cdots \\ + a_M Q_{n-k}^d \\ = \sum_{m=0}^{M-1} a_{n1} Z_m(n) \dots\dots\dots\dots (7) \end{aligned}$$

Where $M = (z+d)!/(z!\,d!)$ is the overall measurement. In Barahona and poon, the voters-winner method's specifics are given. (4) briefly, A range of polynomial "linear and nonlinear" autoregressive models with changing memory and dynamical order is created by the Volterra-Weiner method and are best fitted to predict the data. As a result, each model is parameterized by z and d, which stand for the model's embedding dimension and level of nonlinearity, respectively. $(i.e\ d = 1)$ for a linear and $(d > 1)$ for a nonlinear model. The coefficients are estimated recursively. The normalized residual sum of squared errors is a metric used to assess the goodness of fit of a model "linear or nonlinear":

$$\varepsilon(Z.d)^2 = \frac{\sum_{n=1}^{N} (Q_n^{calc}(Z.d) - Q_n)^2}{\sum_{n=1}^{N} (Q_n - \mu_Q)^2} \quad \dots\dots\dots\dots\dots (8)$$

a variance of the error residuals that are normalized. Using the Akaike data, the top linear and nonlinear models are selected. Theoretical requirement (8) that reduces:

$$G(r) = \log_{\varepsilon}(r) + \frac{r}{N} \quad \dots\dots\dots\dots (9)$$

Where $r \in [1. M]$ is how many polynomial terms there are in a certain pair's$(Z. d)$ shortened Volterra expansion. Z^{linear}search is used to find the optimum linear model for each data series. which minimizes $G(r)$ with $(d = 1)$. Analogously varying $Z^{\text{non-linear}}$ and $(d > 1)$ leads to the best nonlinear model. similar to the original series' autocorrelation and power spectrum, the most effective linear and "nonlinear models" for surrogate randomized data sets are discovered. This results in four competing models with error standard deviations [8]

$$\varepsilon_{orginal}^{linear} \cdot \varepsilon_{orginal}^{non-linear} \cdot \varepsilon_{orginal}^{linear} \cdot \varepsilon_{orginal}^{non-linear}$$

According to the last study, it's said that the human heart is part of a complicated and nonlinear system mathematicians proved that even simple nonlinear rules can cause complex behavior as the rules that govern the cardiovascular system are not simple so the healthy heart is one of the most complicated systems of the world [9]. The study showed that the regular sinus rhthm diagram for heartbeat is not an indication of a healthy person in contrast to what most people might think. Also, the study showed that while people become older the complexity of their heartbeat will decrease.

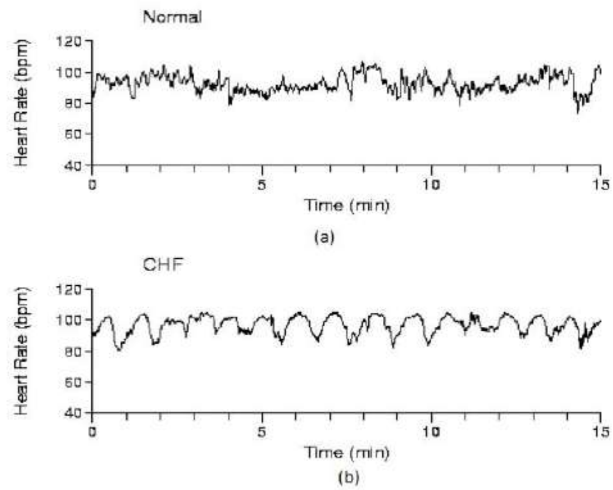

Figure (1) the heartbeat of (a) healthy person (b) with sever congestive heart failure [10]

Figure (1) shows the heart and diagram of a healthy and diseased person. The healthy one shows complex nonlinear behavior while the one with heart failure has aperiodic predictable performance. However, for a person with heart failure, the heartbeat is periodic which means that it can only perform on specific occasions, and while the situation is changed the heart might not get adapted to the new environment hence the person will be in danger [11].

7. Conclusion

Many complex systems_in nature obey chaos theory and nonlinear dynamics. The definitions of chaotic system and the difference between linear and nonlinear system was discussed in this paper. Dealing with a heart is a complex system that obeys the rules of a dynamic system. Researchers have found that heartbeats in healthy young people are completely unpredictable and non-periodic in contrast to the ones for people with heart failure. The explained experiments showed different scaling behavior in healthy and diseased samples. Which is related to the underlying mechanism of the heartbeats dynamics.

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