NEW NONLINEAR ANALYSIS TECHNIQUES FOR VALVULAR HEART DISEASES DETECTION

By

Mahetab Mohamed Salama Ahmed

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
in
Biomedical Engineering and Systems

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Title of Thesis:

New Nonlinear Analysis Techniques For Valvular Heart Diseases Detection

Key Words:

Heart Sounds and Murmurs; Nonlinear Analysis; Phase Space co-occurrence Matrix; Feature Extraction; Classification.

Summary:

In this thesis, we presented and evaluated two new nonlinear analysis techniques to enhance the early detection and diagnosis of heart diseases especially the ones related to the heart valves by introducing new nonlinear feature extraction methods. The first method is based on the phase space analysis that we reconstructed from the heart sound signal. The density matrix of this phase space portrait is generated and further the nonlinear features are extracted. In the second method, we extracted the nonlinear features based on the texture analysis of the two dimensional phase space plot using the co-occurrence matrix. The results of the proposed nonlinear analysis techniques showed that they are promising candidates to be used in computer aided diagnosis (CAD) or monitoring tools for heart diseases. Where, the accuracy of the phase space density matrix method and the phase space co-occurrence matrix methods are 93.96% and 91.63 respectively.

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I would like to express my sincere gratitude to my supervisors, Prof. Dr. Ayman Eldeib and Dr. Walid Al-Atabany, for their knowledge, help, encouragement and most of all for their time.

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Dedication

To The Department of Systems and Biomedical Engineering

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Nomenclature

ANN	Artificial Neural Network
CAD	Computer Aided Diagnosis
CVD	Cardiovascular Diseases
CWT	Continuous Wavelet Transform
ECG	Electrocardiogram
EEMD	Ensemble Empirical Mode Decomposition
EMD	Empirical Mode Decomposition
FD	Fractal Dimension
FN	False Negative
FNN	False Nearest Neighbor
FP	False Positive
FT	Fourier Transform
IVC	Inferior Vena Cava
LA	Left Atrium
LV	Left Ventricle
MI	Mutual Information
MRI	Magnetic Resonance Imaging
NB	Naïve Bayes
PCG	Phonocardiogram
RA	Right Atrium
RP	Recurrence Plot
RQA	Recurrence Quantification Analysis
RV	Right Ventricle

S1	First Heart Sound
S2	Second Heart Sound
S3	Third Heart Sound
S4	Fourth Heart Sound
STFT	Short Time Fourier Transform
SVC	Superior Vena Cava
SVM	Support Vector Machines
TN	True Negative
TP	True Positive
WD	Wigner Distribution
WHO	World Health Organization
WT	Wavelet Transform

Abstract

Cardiovascular diseases are the most common life threatening diseases around the world. Recently, world health organization announced that cardiovascular diseases will be responsible for three-quarters of the total deaths in the world. Auscultation is the fundamental diagnostic tool for heart diseases especially valvular heart diseases. However, listening to heart sounds using stethoscope is not an easy skill to be acquired; besides the diagnosis depends mainly on the physician experience. Therefore, in order to overcome the limitations of the already existing auscultation technique, an automated way for analyzing heart sounds will be more efficient for early detection and diagnosis of heart diseases. Current heart sounds analysis techniques rely basically on traditional methods of features extraction that focus on linear analysis approaches, which are time, frequency and time-frequency domains. However, due to the chaotic behavior of the heart, heart sounds are non-stationary nonlinear signals. In this thesis, two new nonlinear feature extraction methods are developed and evaluated; phase space density and the phase space co-occurrence matrix. Features extracted from the former one are based on the statistical analysis of the reconstructed phase space while features extracted from the later one are calculated from the co-occurrence matrix of the phase space plot of the system. Consequently, our nonlinear analysis approaches will enhance the classification of normal and abnormal heart sounds and further automatically detect heart diseases. Different statistical classifiers are used in the classification process showing promising preliminary results with accuracy of 93.96% and 91.63% for the phase space density matrix and the phase space co-occurrence matrix methods, respectively. This confirms the promising robustness of the new techniques as practical diagnostic and monitoring tool for heart valves diseases.

Chapter 1 : Introduction

1.1. Problem Overview

Cardiovascular diseases (CVD) are group of diseases that affect the heart and blood vessels causing defects to their structures. For many years, the world health organization (WHO) is top listed the cardiovascular diseases as the first cause of death. The total number of CVD deaths is continuously increasing especially in the low and middle income countries. WHO estimated that by 2015 the global number of CVD deaths will be around 20 millions. By 2020, it is expected that the CVD will be responsible for more than three-quarters of the global mortality and the number will continue to increase [1].

Early detection of heart diseases is considered the first and most important step in the treatment process. However, despite all the available diagnosis techniques of CVD such as electrocardiogram (ECG), stress testing, echocardiography, coronary angiography, cardiac catheterization, and cardiac MRI, still there are patients diagnosed in late stages. Most of the advanced diagnostic modalities are only exists in large hospitals because they need well trained operators, relatively high in cost and need large space. Besides, there is almost no diagnostic technique good enough for all heart diseases, for example, ECG measures the electrical activities of the heart but cannot detect the defect of heart valves, which is the main cause of valvular heart diseases that can be easily detected by analyzing the heart sounds [2].

In low and middle income countries especially in rural areas, the only places that can provide medical care are the small healthcare centers with doctors that tend to be general practitioners. In these places, auscultation, the application of stethoscope for the interpretation of heart sounds, is almost the only method available for screening and diagnosis of CVD [3]. Moreover, the detection of heart diseases using auscultation is a very hard skill to be mastered and it takes years of practice given the complex and non-stationary nature of heart sound signals and their variability with different heart conditions. Also, not all heart sounds either normal or abnormal are in the audible range of human ear. Besides, the presence of other factors such as the patient movement and background noises lead to misdiagnosing heart diseases. Where, noises may block the heart sounds and further prevent the doctor from clearly hearing them. Last but not least, it is very hard to extract information by either hearing or visually inspecting the graphical representation of the heart sounds [4].

1.2. Thesis Objective

Motivated and inspired by the above limitations of the current auscultation technique, the primary goal of this thesis is hoping to help the continuously increasing number of CVD patients by providing new computer aided diagnosis (CAD).That is based on heart sounds and can help make the early detection and diagnosis of CVD in an economically efficient automated way. Where checking heart sounds is the first screening methods for all CVD patients.

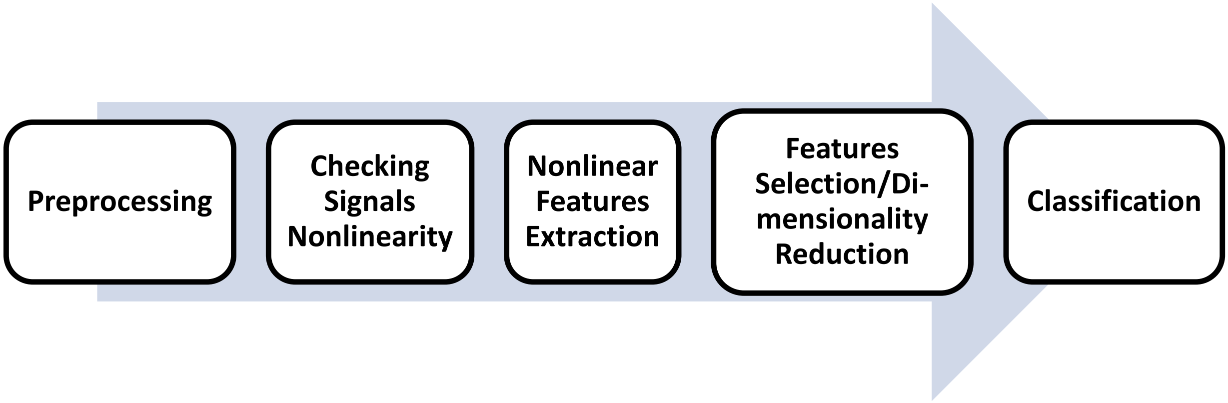

Figure 1.1: Block diagram of the proposed nonlinear analysis methods

We proposed two techniques for the analysis of heart sounds so that they will be the core of the CAD system, which indicated in Figure 1.1. The identification and further the classification of heart sounds are done by applying nonlinear analysis techniques on the heart sound signals to extract a group of nonlinear features. Then, machine learning algorithms are used to classify the signals using the extracted nonlinear set of features. Two new nonlinear methods, phase space density matrix and phase space co-occurrence matrix are developed and evaluated in this thesis for enhancing the discrimination between the normal and abnormal hearts sounds and further the early detection of CVD especially the ones related to the heart valves.

1.3. Medical Background

1.3.1. Anatomy of the heart

The heart is a muscular organ of four chambers connected through four valves. The four chambers are the right and left atriums (atria) and right and left ventricles (ventricles) [4]. The atria are smaller than the ventricles and have thinner, less muscular walls than the ventricles, which are responsible for pumping the blood. The four valves that control the blood flow to or from the heart are aortic, mitral, pulmonary and tricuspid as shown in Figure 1.2. The heart pumps blood through the network of arteries and veins called the cardiovascular system.

1.3.2. Physiology of the heart

The blood is circulated all over the body using the four chambers of the heart. Firstly, right atrium (RA) receives the returning deoxygenated blood from the body through the superior vena cava (SVC) and inferior vena cava (IVC). Then, RA contracts and right ventricle (RV) is filled. The tricuspid valve is closed to prevent back flow of the blood. RV pushes the blood through pulmonary artery and further to the lung. After that, the oxygenated blood is flushed into the left atrium (LA) and when it contracts, the blood is sent to the left ventricle (LV). The mitral valve is closed to prevent the blood to flow back to the atrium. LV contracts causing the aortic valve to open so that the blood can flow to the body [5].