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Classification of heart sound signal using curve fitting and fractal dimension

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ABSTRACT

Cardiovascular disease is one of the major causes of mortality worldwide. Audio signal produced by the mechanical activity of heart provides useful information about the heart valves operation. To increase discriminability between heart sound signals of different normal and abnormal persons, extraction of appropriate features is so important. An accurate segmentation of heart sound signal requires its corresponding ECG[1] signal. But, acquiring of ECG is generally expensive and time consuming. So, one of the main goals of this paper is to eliminate the segmentation step. In this paper, two feature extraction methods are proposed. In the first proposed method, curve fitting is used to achieve the information contained in the sequence of heart sound signal. In the second method, the powerful features extracted by MFCC[2] are fused with the fractal features by stacking. The experiments are done on six popular datasets to assess the efficiency of different methods One of the data sets contains four classes and the rest of them include two classes (normal and pathologic). In the classification step, the nearest neighbor classifier with Euclidean distance is used. The proposed method has good performance compared to previous methods such as Filter banks and Wavelet transform. Particularly, the performance of the second method is significantly better than the first proposed method. For three data sets, the overall accuracy of 92%, 81% and 98% are achieved, respectively.

1. Introduction

The heart is a vital organ of body and statistics show that the first cause of mortality in the world, which is equal to 29 percent of all deaths, is caused by cardiovascular disease [1]. According to the CDC[3] in 2012, eleven percent of adults suffer from heart disease, which is the highest percentage compared to other diseases [2]. The sound of the heart can describe the mechanical activity of the heart. According to pathological conditions in heart, the characteristics of heart sound signal are changed. The changes in the PCG[4] signal occur before their symptoms. So, the diagnosis will be in the early stages. Today, the diagnosis of heart disease is dependent on the advanced technologies such as echocardiography and cardiac MRI. These technologies are expensive and also they cannot be used as a portable device [3]. Traditionally, auscultation is a noninvasive, cheap and simple method for diagnosing diseases. Auscultation is the monitoring of sounds heard over the chest walls, which is usually done by the stethoscope. The heart sound can be measured by phonocardiography. In addition, the analog or digital stethoscope can be used for listening the heart sound signal. Stethoscope is a simple instrument to convey the heart sounds from the chest to the ear of examiner.

A healthy heart has two clear sounds called first sound (S1) and the second sound (S2). By closing the mitral and tricuspid valves, S1 is produced at the beginning of ventricular contraction. S2 is produced due to the closure of aortic and pulmonary valves. Murmurs sounds are heard because of return of blood back through leaky valve (regurgitation), ventricular septal defect or arterial venous connection, the forward flow through narrow or deformed heart valves (stenosis), or due to the high speed of blood flow through the normal or abnormal valve. Different diseases may cause the audible murmur in different parts of the cardiac cycle. In general, murmurs are divided into two categories called systolic and diastolic. Due to the human hearing limitation and transient and non-stationary nature of PCG signal, diagnosis based on heart sound through a stethoscope requires to experience and skill. Therefore providing

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[1] Electrocardiogram
[2] Mel frequency cepstrum coefficients
[3] Centers for disease control and prevention
[4] Phonocardiogram

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a system that can properly do primary diagnosis with the lowest cost is desirable.

Two algorithms for feature extraction and classification of heart sound signal (PCG) are proposed in this paper. In the first proposed algorithm, the information of PCG signal sequence is obtained by using the curve fitting method. Coefficients calculated in this way are used as features.

Murmur is an obvious symptom of disease. Murmurs are high frequency sounds. This means that they are intensively changed. Simply, it can be said that signal is more crumpled in the location of murmur. In addition, the PCG signal is self-similar. In the second suggested method, the PCG signal is considered as a fractal signal where the fractal dimension is a measure of signal complexity. Previous studies have shown that MFCC as an audio processing technique has good results on the heart beat signal [4]. So, to provide the advantages of MFCC, the final feature vector in the second proposed method is obtained by merging the fractal and MFCC features. In the last section, the proposed methods are compared with previous studies [5,6].

2. Material and methods

Extensive studies have been done on the PCG signal. They are looking for suitable features that can express the characteristics of the signals as well. Timing, morphology and frequency could determine PCG signal characteristics [7]. Heart sound signal can be considered as a type of time series. Time series are the consecutive sequence of points recorded at regular time intervals. There are several ways to describe time series: time methods, frequency methods and time-frequency methods. The example of time features is given in [7]. In this work, after the segmentation of PCG signal using ECG, certain parts of the normalized energy of Shannon are considered as extracted features.

Studies on extraction of frequency components were usually very complicated up to 1970. In 1976, the FFT technique was used for analyzing the frequency of the heart sounds. In 1986, the non-parametric methods for frequency analysis is improved to the parametric methods such as AR.[5] and ARMA[6] Gabor suggested that representation of the signal in both time and frequency domain will be more useful because time-frequency analysis provides more information. Wavelet transform is widely used in various phases of the heart sound signal analysis as a method of time-frequency [8,9]. Author in [10] concluded that “Morlet” wavelet has the best result by applying 8 common type of mother wavelets on 10 heart sounds with different pathological conditions. Author in [11] has done Heart murmurs detection and classification with the help of wavelet and Hilbert transforms. In [9], a new mother wavelet which is similar to PCG signal is used to feature extraction. Author in [12] used the 6-th order Daubechies wavelet for estimating the heart cycle. Then, average Shannon energy envelope is calculated for reconstructed signal.

A method based on scaled spectrogram and partial least squares regression was proposed for feature extraction. In some cases, the nature and the form of signal are changed in different periods. In these cases, more flexibility is needed. So that, in addition to change in the scale and the form of basic functions, overall deformation is required. The main motivation of the matching pursuit method, introduced by “Mallat” in 1993 by, was to solve this problem [13]. Author in [14] proposed a new mathematical model to simulate systolic murmur. Modeling murmurs to time-frequency atoms is done by using multivariate matching pursuit method. The model parameters obtained from the signal are used for feature extraction. Author in [15] has used matching pursuit method to decompose PCG signal into a series of TF[7] atoms. Atoms are chosen from a redundant dictionary. Then selected atoms were clustered and components of the murmurs were identified. At the end, features were generated using Wigner-Ville distribution.

In recent decades, some time series have been described based on chaos theory. In this theory, the behavior of a dynamic system is sensitive to initial conditions. To describe this behavior, the concepts such as Lyapunov exponent are presented. Calculating fractal dimension is one of the methods of analyzing signals such as PCG. Fractal dimension is used in both segmentation and feature extraction. There are many methods to estimate the fractal dimension. One of the most important fractal analysis methods among the usual fractal estimation methods that can be implemented for real-time systems is the VFD[8][16]. In [17], techniques such as wavelets, Shannon energy, recurrence quantification analysis, and fractal dimensions were used for extraction of 207 features. A multi-domain subset consisting of 14 features has been derived by using Pudil's SFFS[9] method. In [18] a set of 17 features extracted in the time, frequency and in the state space domain has been suggested. In many studies, a method has been used for segmentation after pre-processing and then features were obtained from each cycle. Segmentation is one of the faced difficulties in the heart sound signal classification. Among the various algorithms that have been developed in this area, most of them use the ECG signal which is recorded simultaneously with the PCG signal [19]. Segmentation using ECG signal have problems. PCG and ECG recording is not available in many cases, especially when the portable recording devices are used outside the clinic [20]. ECG signals are sometimes impaired by some heart diseases, such as ventricular hypertrophy. Abnormalities in ECG signal causes an error in segmentation [21]. The main reason for paying a special attention to the heart sound signal is that it can be available inexpensively. The main goal is that we can have an inexpensive, correct and early detection, which can be implemented in deprived areas, while using the ECG signal doesn't satisfy this goal. There are other methods for segmentation too. These methods will be less costly due to using just PCG signal, but they are less reliable. Due to different amplitude-levels of heart signals and background noise, selection of an efficient set of thresholds is a challenging task in most of the segmentation approaches [22]. Among these methods, segmentation by extracting the envelope is more common [19,23]. In [24], the boundaries of heart sounds, i.e., s1, s2, s3 and s4, and heart murmur are determined by using the envelope computation, Shannon entropy, the total variation filtering, the instantaneous phase based boundary determination and the boundary location adjustment. Other achievements are based on statistical models [25]. For implementation of these methods on different datasets, several parameters must be set and because of that we want to eliminate the segmentation step.

A brief description of methods that we have compared our work with them is given in the following:

2.1. Wavelet

Author in [5] has extracted features by using the wavelet transform. For extracting nf features, each signal is decomposed to $nf-1$ levels. So $nf-1$ detail coefficients and one approximate coefficient

[5] Autoregressive
[6] Autoregressive moving average model
[7] Time-frequency
[8] Variance fractal dimension
[9] Sequential floating forward selection