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A new approach to early diagnosis of congestive heart failure disease by using Hilbert–Huang transform

Gokhan Altan [a,*], Yakup Kutlu [b], Novruz Allahverdi [c]

[a] Mustafa Kemal University, Antakya, Turkey
[b] Iskenderun Technical University, İskenderun, Turkey
[c] Karatay University, Karatay, Turkey

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ABSTRACT

Congestive heart failure (CHF) is a degree of cardiac disease occurring as a result of the heart's inability to pump enough blood for the human body. In recent studies, coronary artery disease (CAD) is accepted as the most important cause of CHF. This study focuses on the diagnosis of both the CHF and the CAD. The Hilbert–Huang transform (HHT), which is effective on non-linear and non-stationary signals, is used to extract the features from R-R intervals obtained from the raw electrocardiogram data. The statistical features are extracted from instinct mode functions that are obtained applying the HHT to R-R intervals. Classification performance is examined with extracted statistical features using a multilayer perceptron neural network. The designed model classified the CHF, the CAD patients and a normal control group with rates of 97.83%, 93.79% and 100%, accuracy, specificity and sensitivity, respectively. Also, early diagnosis of the CHF was performed by interpretation of the CAD with a classification accuracy rate of 97.53%, specificity of 98.18% and sensitivity of 97.13%. As a result, a single system having the ability of both diagnosis and early diagnosis of CHF is performed by integrating the CAD diagnosis method to the CHF diagnosis method.

1. Introduction

An electrocardiogram (ECG) is a signal that records the electrical changes within the heart at regular intervals. Electrodes with different characteristics are used to obtain ECG signals (ECGs) from various parts of the body (arms, legs, chest, etc.). The horizontal plane of the ECG is time; the vertical plane is the amplitude of the electrical potential [1]. The ECG varies in frequency band from 0.5 Hz to 100 Hz and varies in amplitude value from 0 mV to 5 mV [2,3]. The ECG is used consistently for the monitoring and diagnosis of atrial and ventricular conduction disorders, rhythm disturbances and pericarditis, heart-related diseases and other systemic functions in the management of cardiac pacemakers [4]. The ECG has a very crucial role in monitoring and diagnosis of heart diseases. The ECG taken during the monitoring process is very important for the identification of abnormalities that may occur with complications. Therefore, the analysis, storage and transmission processes on the ECG in clinical applications have nowadays become intensively studied [5].

Electrical impulses occur as a result of polarization and depolarization. These impulses are presented as P, Q, R, S and T waves, as seen in Fig. 1 [6]. The sections between the waves are called segments; the distance between the waves is called an interval [1]. A P wave occurs as a result of the depolarization

* *Corresponding author.* Mustafa Kemal University, Antakya, Turkey. Fax: +90 (326) 613 56 13.
E-mail address: gokhan_altan@hotmail.com (G. Altan).

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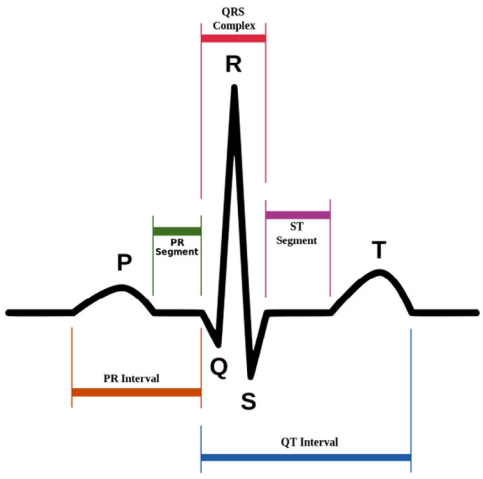

Fig. 1 – P, Q, R, S, and T waves on ECG.

of the atrium. The duration of the P wave is about 0.11 s and its amplitude varies from 0.18 mV to 0.22 mV in a normal derivation [7].

A QRS complex occurs as a result of the depolarization of the ventricle. The Q wave is the first negative wave and the R wave is the first positive one after the P wave. The S wave is the first negative wave after the R wave. The different QRS complex forms are seen in different derivations. The QRS complexes have significant meaningful differences even among normal subjects [8]. The QRS complex has the maximum amplitude in an ECG waveform. Duration of a QRS complex does not exceed 0.11 s and its amplitude is about 2–3 mV [7]. A T wave occurs as a result of the repolarization of the ventricles. The duration of the T wave may vary from 0.10 s to 0.25 s in a normal subject [8].

The studies in recent years have shown the significant relationship between autonomic nervous system (ANS) and cardiovascular cases. Heart rate variability (HRV) is a method for evaluating the ANS functionality of the sinus node level. The HRV is a measurement of the time-domain and the frequency-domain of beat-to-beat intervals. Beat-to-beat intervals are the length of time between two consecutive R waves. The time-domain methods usually use the avarage of normal-to-normal heartbeats. The frequency-domain methods are based on how the power of the ECG changes with a function of the frequency [9]. All the computable basic time-domain and the frequency-domain HRV measures were widely explained in the literature [9,10].

Congestive heart failure (CHF) is also known as heart failure. The CHF is a cardiac disease in which a heart does not have the ability to provide adequate metabolic cardiac output that a human organism needs. In the case of metabolic needs, the heart can increase the flow capacity by 200–600%. When the flow capacity of the heart is exceeded or increased, it cannot meet metabolic needs of subjects with CHF [11]. Doctors may recommend one or more of the following ways to diagnose the CHF: ECG, stress testing, echocardiography, B-type natriuretic peptide blood test, ejection fraction and cardiac catheterization.

Coronary artery disease (CAD) is a pathological condition where the diameter of the arteries decreases because of the cholesterol plaque on the heart wall. In this case, arteries cannot supply nutrients and oxygen to heart muscles [12]. He et al. [13] in the United States and Baldasseroni et al. [14] in Italy found that the CAD is the most risky factor for the CHF. This case has revealed the necessity for diagnosis of the CAD to early diagnosis of the risks for CHF. Doctors may recommend one or more the following ways to diagnose the CAD: ECG, stress testing, echocardiography, chest X-ray, blood tests (apolipoprotein A1, fibrinogen, urine albumin/creatinine ratio), coronary angiography and cardiac catheterization.

In literature, there are various methods to detect ECG disorders. Features were extracted by applying various methods to the ECG like diagnosing arrhythmia using morphological features of QRS complexes and R waves [15]. The features of these disorders were also extracted using wavelet transform [16,17]. Both wavelet transform and Fourier analysis were applied to ECG beats [18]. One method was used, morphological features of P, Q, R, S and T waveforms [19–21], whereas another worked on the phase space portraits of 3-lead ECG from subjects [22]. In addition, the template matching [23] and principal component analysis (PCA) methods [24,25] were used and both of them were applied to various signal processing problems. Many methods such as wavelet analysis, discrete Fourier transform, empirical mode decomposition (EMD), second order difference plot, wavelet packet decomposition are used to analyze nonlinear biomedical signals. One of the most well-known methods is the Hilbert–Huang transform (HHT) measurements. The HHT is a relatively new method used in biomedical data analysis. This transformation is applicable to non-linear and non-stationary signals. In recent studies, the HHT is applied to electroencephalography (EEG) signals to diagnose diabetes [26] and to predict epileptic seizure [27]. The HHT is also applied to audio signals for extracting features and filtering processes [28], the digital modulation classification for spectrum sensing [29], and to the ECG signals to diagnose atrial fibrillation [30] and the CHF [31]. In this study, HHT would be used to design an effective statistical feature extraction model using ECG to provide diagnosis and early diagnosis of the CHF. Thus, high-dimensional feature vectors that are formed in combination with instinct mode functions (IMFs) can be interpreted using the statistical analysis on the diagnosis and early diagnosis of the CHF.

The CHF and the CAD have been the subjects of some studies. A set of medical examinations and clinical tests are needed for the definitive diagnosis of the CHF. While some of the studies on CHF focused on determining the risk factor of death [32–34], some of them focused on the diagnosis of the CHF using the HRV measures [10,35,36]. The studies could separate CHF patients and normal subjects using the short-term HRV measures, wavelet entropy values, time domain measures and Poincaré plot measures [10], using the spectral analysis of HRV with autonomic changes model to diagnose risk of the CHF [32]; using features obtained applying wavelet transform and power spectral destiny (PSD) for R-R intervals [37]; using equal frequency in amplitude and equal width in time discretization [38]; using low and high frequency components, standard deviation (SD) of R-R intervals, daytime, nighttime and sub-maximal heart rate of HRV [34]; and using the features obtained applying linear discrimination analysis and the HRV measures [35]. Like the CHF, a set of medical examinations and clinical tests are needed for definitive diagnosis