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Computer-assisted diagnosis for chronic heart failure by the analysis of their cardiac reserve and heart sound characteristics

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ABSTRACT

An innovative computer-assisted diagnosis system for chronic heart failure (CHF) was proposed in this study, based on cardiac reserve (CR) indexes extraction, heart sound hybrid characteristics extraction and intelligent diagnosis model definition. Firstly, the modified wavelet packet-based denoising method was applied to data pre-processing. Then, the CR indexes such as the ratio of diastolic to systolic duration (D/S) and the amplitude ratio of the first to second heart sound (S1/S2) were extracted. The feature set consisting of the heart sound characteristics such as multifractal spectrum parameters, the frequency corresponding to the maximum peak of the normalized PSD curve (f_{PSDmax}) and adaptive sub-band energy fraction (*sub_EF*) were calculated based on multifractal detrended fluctuation analysis (MF-DFA), maximum entropy spectra estimation (MESE) and empirical mode decomposition (EMD). Statistical methods such as *t*-test and receiver operating characteristic (ROC) curve analysis were performed to analyze the difference of each parameter between the healthy and CHF patients. Finally, least square support vector machine (LS-SVM) was employed for the implementation of intelligent diagnosis. The result indicates the achieved diagnostic accuracy, sensitivity and specificity of the proposed system are 95.39%, 96.59% and 93.75% for the detection of CHF, respectively. The selected cutoff values of the diagnosis features are $D/S = 1.59$, $S1/S2 = 1.31$, $\Delta\alpha = 1.34$ and $f_{PSDmax} = 22.49$, determined by ROC curve analysis. This study suggests the proposed methodology could provide a technical clue for the CHF point-of-care system design and be a supplement for CHF diagnosis.

1. Introduction

Chronic heart failure (CHF) occurs in the situation that heart loses the ability to pump adequate oxygen-rich blood to meet the need of peripheral tissues and organs of the body. This may cause some symptoms such as shortness of breath, tiredness, irregular heartbeats, etc. Compared to the expensive imageological diagnosis and biochemical analysis, it is of great significance to develop a non-invasive, low-cost and convenient detection method for CHF diagnosis.

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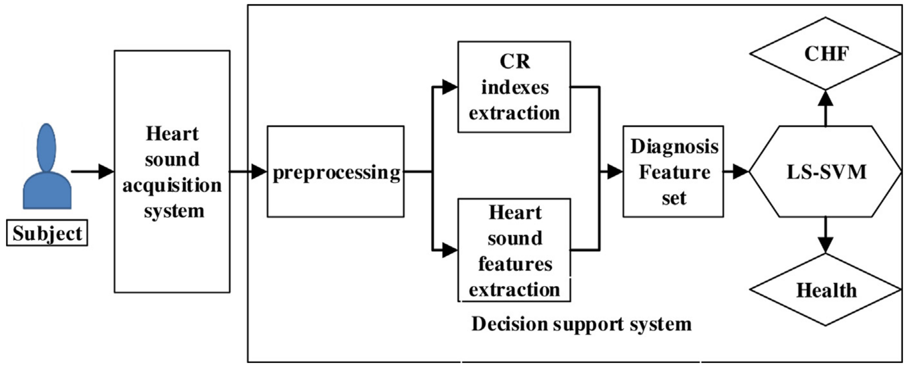

Fig. 1 – The schematic of the computer-assisted diagnosis system for CHF.

Many researchers have devoted themselves to the studies on computer-assisted diagnosis for CHF based on the detection and analysis of Electrocardiograph (ECG). Ivanov et al. [1,2] and Dutta [3] have found there are both a loss of multifractality in heartbeat sequences and ECG of the patients with CHF. The prolongation duration of QRS or wide QRS/T angles could be a predictive indicator of CHF [4,5]. Skrabal et al. [6] used ECG detection combined with bio-impedance measurement technique to diagnose CHF. However, ECG can only detect the cardiac chronotropic and dromotropic action instead of the cardiac inotropic action that is reduced significantly in CHF patients [7], so it can be seen that single ECG detection for the diagnosis of CHF is insufficient.

Heart sound is very important as it directly reflects the mechanical properties of heart activity [8,9]. The studies on the relationship between heart sound and cardiac contractility indicate that the amplitude of the first heart sound (S1) is positively correlated with the maximum rise rate of left ventricular pressure ($r = 0.9551$, $p < 0.001$) and the amplitude of S1 is also closely related to the strength of cardiac contractility [10,11]. This has suggested that the amplitude of S1 can reflect the level of cardiac contractility. The most important aspect of cardiac dysfunction in heart failure is not the depressed cardiac performance observed at basal resting state but rather the loss of cardiac reserve (CR) [12,13], which is manifested in the decrease of cardiac contractility, so the detection and analysis of heart sound and the measurement of CR could provide important clues for the diagnosis of CHF. Based on the relationship between heart sound and cardiac contractility, an noninvasive and quantitative method for the assessment of CR has been proposed by our group [14,15]. Some diagnostic techniques such as real-time transmission of the phonocardiogram (PCG) through the Internet and computer-assisted auscultation were developed [16,17]. The application of CR indexes in monitoring and evaluating heart function for gestational woman was implemented [18]. However, until now, the studies about the application of CR in the diagnosis of CHF have not been reported, and the utilizations of heart sound characteristics for the diagnosis of CHF are few, except that an appearance of the third heart sound is regard as a highly specific and none sensitive marker for the diagnosis of CHF [19,20].

In this paper, an intelligent diagnosis system for CHF diagnosis was proposed, the schematic of which is shown in Fig. 1. It consists of acquisition system (hardware) and decision support system (software). The acquisition system includes sensor, acquisition circuit and computer device shown in Fig. 2. The decision support system is embedded in the computer. This paper emphatically introduces the decision support system that includes the following parts. The preprocessing is implemented based on amplitude normalization and modified wavelet packet denoising methods. The CR indexes such as the ratio of diastolic to systolic duration (D/S) and the amplitude ratio of the first to second heart sound (S1/S2) combined with three heart sound characteristics such as the frequency corresponding to the maximum peak of the normalized PSD curve (f_{PSDmax}), adaptive sub-band energy fraction (sub_EF) and multifractal spectrum parameter were proposed to structure a diagnostic feature set. The self-developed cardiac reserve monitor software (CRM version1.0, Chongqing University and Bo-Jing Medical Informatics Institute, China) was used to measure the CR indexes, and the heart sound characteristics were extracted based on maximum entropy spectra estimation (MESE), empirical mode decomposition (EMD) and multifractal detrended fluctuation analysis (MF-DFA) methods which are good at the analysis of non-stationary and non-linear physiological signal [21–23]. The LS-SVM was determined as the classifier of proposed system by the comparison of performances with back-propagation artificial neural network (BP-ANN) and hidden markov model

Fig. 2 – Cardiac reserve monitor used in this study.