Biomedical Signal Processing and Control 40 (2018) 324–334

Contents lists available at ScienceDirect

Biomedical Signal Processing and Control

journal homepage: www.elsevier.com/locate/bspc

Research Paper

Automated technique for coronary artery disease characterization and classification using DD-DTDWT in ultrasound images

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ARTICLE INFO

Article history:
Received 16 January 2017
Received in revised form 28 June 2017
Accepted 30 September 2017

Keywords:
Coronary artery disease
Computer aided diagnosis
Double density-dual tree discrete wavelet transform
Entropy

ABSTRACT

Heart is one of the important as well as hardest working organ of human body. Cardiac ischemia is the condition where sufficient blood and oxygen will not reach the heart muscle due to narrowed arteries of the heart. This condition is called coronary artery disease. Several non-invasive diagnostic tests fail to reveal exact impact of coronary artery disease on myocardial segments. The ultrasound images can explore major impact on ventricular muscle segments due to ischemia and complication of acute coronary syndrome. Computer aided diagnosis tools can predict coronary artery disease in its early stage so that patients can undergo treatment and save their life. This paper presents a novel computer aided diagnosis system for the automated detection of coronary artery disease using echocardiography images taken from four chamber heart. Proposed method uses double density-dual tree discrete wavelet transform (DD-DTDWT) to decompose the images into different frequency sub-bands. Then various entropy features are extracted from these sub-bands. The obtained dimension of the features is reduced using marginal fisher analysis (MFA) and optimal features are selected using feature ranking methods. The proposed method achieved promising accuracy of 96.05%, sensitivity of 96.12%, and specificity of 96.00% for linear discriminant classifier using entropy ranking method with *twelve* features. We have also proposed coronary artery disease risk index (CADRI) to categorize diseased subjects from normal subjects using a single value. Thus, it can be used as a diagnosis tool in hospitals and polyclinics for confirming the findings of clinicians.

1. Introduction

Ischemic heart disease is a condition where affected segment of cardiac muscles will show varying degrees of reduced contractile performances. The coronary artery plaque deposition and narrowing of lumen carries major course in the development of myocardial ischemia. The coronary artery disease is a vast cohort where patient can be identified incidentally without any symptoms or chest pain on exertion, or myocardial infarction (MI). Hence, the presence of coronary artery disease can range from subclinical disease to acute myocardial infarction [1]. The acute coronary syndrome possess acute damage to cardiac muscle that produce angina and related symptoms [2]. The diagnosis of this clinical syndrome can be made by electrocardiogram (ECG), cardiac biomarkers, echocardiography, coronary angiogram and intravascular ultrasound (IVUS) for definite evaluation [3]. Interruption in antegrade coronary flow leads to infarction of respective coronary territory. Routine evaluation through ECG and echocardiography in these scenarios have been demonstrated as the best tool in assessing extent of myocardial damage. Apart from these, invasive technique coronary angiogram can be used to explore the information on culprit vessel among MI patients [4]. Although earlier studies have demonstrated that manifestation of coronary artery disease is not uniform, large number of them will be in latent asymptomatic stage that results in subtle myocardial damage [2,5,6]. Diagnosis of these stable coronary artery lesions can be

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https://doi.org/10.1016/j.bspc.2017.09.030
1746-8094/

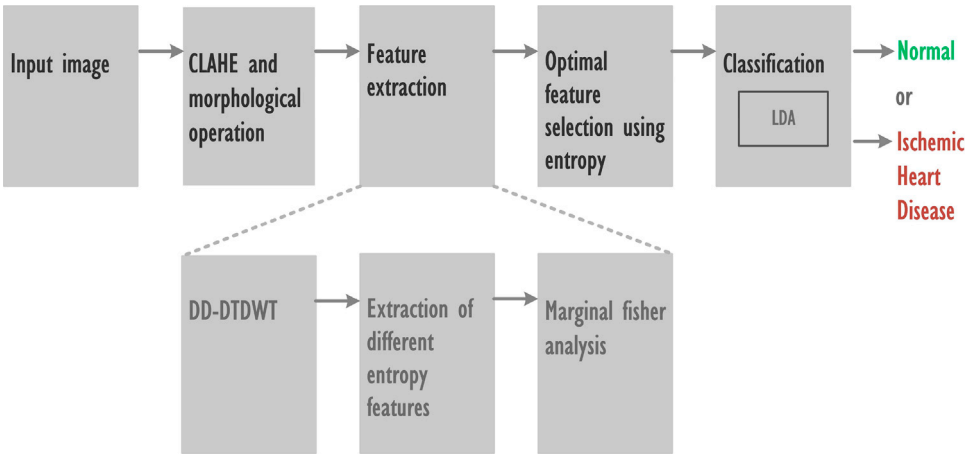

Fig. 1. Illustration of proposed scheme.

Table 1
Dataset descriptions.

Subjects	Total Samples	Male Patients	Female Patients	Age Range (Years)
Normal	150	35	15	28–79
IHD	129	36	07	30–79

done using multiple non-invasive modalities. Screening of this significant stable coronary artery lesion can be made by presence of stress induced myocardial ischemia, where stress can be generated either by exercise or pharmacological agents. Imaging modalities such as ECG, echocardiography, magnetic resonance imaging (MRI) demonstrates various ischemic signs in different stages of stress when compared with resting conditions [7]. The treadmill exercise test (TMT) establishes the diagnosis and estimates the prognosis of chronic stable coronary lesion. The ECG finding of down sloping/horizontal ST segment depression on TMT holds sensitivity and specificity of 68% and 77% respectively in the diagnosis of significant coronary artery disease [8] Among all the imaging modalities in the screening of coronary artery disease, stress echocardiography is best used in the diagnosis (>50% occlusion in coronary artery lumen as found in coronary angiogram) as well as to predict the prognosis of patients with the sensitivity of 88% and specificity of 83%. Stress echocardiography modality found to be better diagnostic tool as compared to nuclear imaging method [9].

Computer aided diagnosis for coronary artery disease has played a major role in the recent years and many studies have been developed using artificial intelligence algorithms [66–68]. In [10], the combination of fuzzy and probabilistic uncertainty measures are able to diagnose the coronary artery disease ECG signals with 86% accuracy. Karimi et al. [11] have analysed heart sounds using wavelet analysis and neural networks and achieved detection accuracies of 90% and 85% for normal and coronary artery disease classes respectively. In [12], empirical mode decomposition (EMD)-teager energy operator (TEO) are used to estimate the heart murmur and obtained an accuracy of 85%. In [13], principal component analysis (PCA) is used to reduce the dimension of the exercise stress testing data and achieved a diagnostic accuracy of 79.71% with SVM classifier. Same group have extended their work by using binary particle swarm optimization (BPSO) and genetic feature selection algorithms and resulted in better accuracy of 81.46% using BPSO with SVM [14]. In [15], the features such as demographic and history data and laboratory examination are used in order to develop decision support system. They have achieved an average sensitivity of 80%, specificity of 65%, and accuracy of 73%. Chu et al. [16] have used coronary artery disease-related risk factors for Bayesian modeling and showed area under curve of 86.2%. For the University California Irvine database Setiawan et al. [17] achieved an accuracy of 87% with fuzzy decision support system.

In [18], descriptors such as recurrences percentage, mutual information, fractal dimension, and embedding dimension error are significantly different in normal subjects and coronary artery disease patients. The methods presented in [19–21] evaluated the ECG signals obtained from three recumbent positions, such as the supine, left and right lateral positions. In [22], heart rate (HR) feature set based carotid arterial wall thickness is proposed and reported an accuracy of 85–90%. The recent study showed variations in voice parameters like spectrogram, long term average spectrum (LTAS), jitter, shimmer, amplitude perturbation quotient (APQ) of the coronary artery disease patients as compared to the normal people [23]. The methods such as, higher order spectra [24], empirical mode decomposition [25], and variants of wavelet transforms [26–29] are also applied to analyse the ECG signals. Patidar et al. [27] have used tunable-Q wavelet transform and correntropy with SVM and achieved an accuracy of 99.72%. Recently, in [29] flexible analytic wavelet transform and cross information potential features are used and reached a promising accuracy of 99.60%.

As a new attempt, Acharya et al. [30] have proposed a computer aided diagnostic tool using different gray scale features extracted from echocardiography images. They have obtained an accuracy of 100% using Gaussian Mixture Model (GMM) using 30 normal and 30 coronary artery disease subjects. In [30] authors have revealed the use of echocardiography images which will inhibits more reliable results without paying much attention on the data acquisition. Though the method achieved maximum performance, it is difficult to generalize due to limited number of subjects taken during the study. The novelty of this paper is, a new paradigm for the diagnosis of coronary artery disease using double density – dual tree discrete wavelet transform (DD-DTDWT) and entropy features, followed by a natural combination of features and graph embedding under MFA framework to enhance the discrimination power among *two* classes. Also we propose a novel formulation, CAD risk index (CADRI) using significant features. Fig. 1 gives the structure of the proposed technique.

2. Materials and methods

2.1. Data acquisition

Totally, 279 ultrasound images are collected from 50 normal and 43 IHD subjects (Total: 93 subjects) based on symptoms and assessment of left ventricular ejection fraction (LVEF). The LVEF