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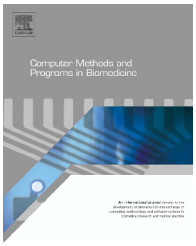

Automated classification of patients with coronary artery disease using grayscale features from left ventricle echocardiographic images

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ABSTRACT

Coronary Artery Disease (CAD), caused by the buildup of plaque on the inside of the coronary arteries, has a high mortality rate. To efficiently detect this condition from echocardiography images, with lesser inter-observer variability and visual interpretation errors, computer based data mining techniques may be exploited. We have developed and presented one such technique in this paper for the classification of normal and CAD affected cases. A multitude of grayscale features (fractal dimension, entropies based on the higher order spectra, features based on image texture and local binary patterns, and wavelet based features) were extracted from echocardiography images belonging to a huge database of 400 normal cases and 400 CAD patients. Only the features that had good discriminating capability were selected using *t*-test. Several combinations of the resultant significant features were used to evaluate many supervised classifiers to find the combination that presents a good accuracy. We observed that the Gaussian Mixture Model (GMM) classifier trained with a feature subset made up of nine significant features presented the highest accuracy, sensitivity, specificity, and positive predictive value of 100%. We have also developed a novel, highly discriminative *HeartIndex*, which is a single number that is calculated from the combination of the features, in order to objectively classify the images from either of the two classes. Such an index allows for an easier implementation of the technique for automated CAD detection in the computers in hospitals and clinics.

1. Introduction

Coronary Artery Disease (CAD) is a condition wherein plaque deposits in the inner walls of the coronary arteries. When these arteries narrow down due to the deposit, the amount of blood flow and oxygen supply to vital organs becomes reduced, and eventually, angina and heart failure occur. It is a disease with a very high mortality rate. Unfortunately, in the early stages of this disease, there are generally no symptoms.

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Therefore, screening and monitoring of the progress of this condition is the best way to detect and treat it, and thereby, reduce the mortality rate.

There are several clinically tried and tested techniques to detect the presence of CAD [1–4,41]. Invasive coronary angiography is the gold standard technique for CAD diagnosis. However, in this technique, the catheter that is inserted as part of the examination might pierce an artery or may remove some plaque from the artery walls and result in embolism, and therefore, increase the risk of stroke. One of the most commonly practised non-invasive techniques for CAD detection is the Exercise Stress Test (EST). However, EST has limited use as most patients will not be able to reach the heart rate required for this test [1] and also EST recorded less sensitivity of 66% for CAD detection [2]. Other techniques include Single-Photon Emission Computed Tomography (SPECT), Positron Emission Tomography (PET), and multi-slice Computed Tomography (CT) [3]. Al Moudi et al. [4] conducted a systematic review of published studies to investigate the diagnostic value of SPECT, PET, and PET/CT in CAD detection. The study reveals the following mean values of sensitivity, specificity and accuracy of these imaging modalities: 82%, 76%, and 83% for SPECT; 91%, 89%, and 89% for PET; and 85%, 83%, and 88% for PET/CT. However, most of these techniques use radioactive material which restricts repeated examinations. Other limitations include higher cost and time of examination. Therefore, efficient, inexpensive, radiation-free, fast and safe non-invasive techniques are needed to diagnose CAD.

The Heart Rate Variability (HRV) technique measures beat to beat intervals in the heart rate [43], and it has been used to diagnose several cardiovascular and non-cardiovascular diseases [5,6]. Compared to healthy subjects, the time and frequency domain measures of HRV have been found to be lower in CAD patients [7]. However, these measures may not always classify normal and CAD cases accurately as they are sensitive to noise. Studies that have developed techniques with the assumption that the cardiac system is nonlinear have demonstrated that nonlinear parameters derived from HRV help detect the presence of CAD [8–10]. Several other computer based techniques for CAD detection have been summarized in the discussion section. We observed that the accuracy of detection is only around 90%. In order to improve this accuracy, we designed a novel approach in which we work on echocardiography images of coronary artery, extract several nonlinear features from these images, and use the resultant significant features in supervised classifiers.

The methodology is illustrated in Fig. 1. The off-line classification system uses the features extracted from the training images and the respective ground truth labels of whether the image is normal or CAD and determines the training parameters of several classifiers. In the on-line system, these training parameters are applied on the features extracted from the test images in order to determine the class label of the test images. The predicted class labels are compared with the actual ground truth class to calculate sensitivity, specificity, accuracy, and Positive Predictive Value (PPV) of the classifier. In both systems, the grayscale features are the following: fractal dimension, entropies based on the higher order spectra, features based on image texture and local binary patterns, and wavelet based features. The classifiers evaluated in this

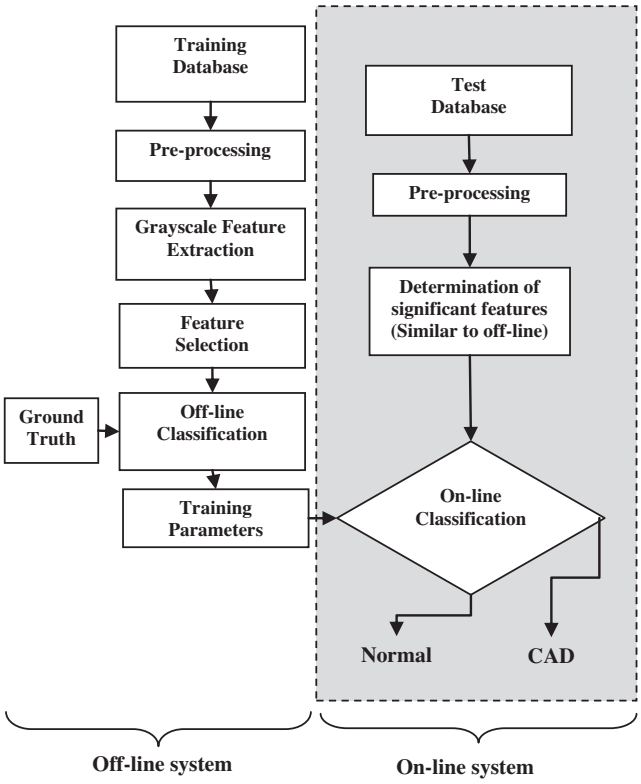

Fig. 1 – Block diagram of the proposed tool for classification of CAD and normal images.

work include Decision Tree (DT), Fuzzy Sugeno (FS), Gaussian Mixture Model (GMM), K-Nearest Neighbor (KNN), Naive Bayes Classifier (NBC), and Radial Basis Probabilistic Neural Network (RBPNN).

In the next section, we describe the image acquisition protocol, extracted features, evaluated classifiers, and give a brief note on the feature selection test called *t*-test and describe the performance measures. Section 3 presents the selected significant features, classification results, and the range of the *HeartIndex* for the normal and CAD classes. Section 4 contains a discussion on the relevant previously published studies and a comparison of the proposed technique with other published work. We conclude the paper in Section 5.

2. Materials and methods

2.1. *Image acquisition*

Echocardiography images from 400 normal images of 30 subjects and 400 CAD images of 30 affected patients were acquired using the Vivid 7 Dimension modality from GE Healthcare. The age range of the normal group was from 20 to 45 years and that of the CAD group affected by ischemic heart disease was from 35 to 65 years. Study approval was obtained from the Institutional Review Board and all patients provided an informed consent. CAD was detected using multiple diagnostic modalities. First, the patient was subjected to routine 12-lead electrocardiogram which documents the ischemic changes, and a detailed clinical evaluation was performed. Then, the