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Automatic assessment of mitral regurgitation severity based on extensive textural features on 2D echocardiography videos

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ABSTRACT

Heart disease is the major cause of death as well as a leading cause of disability in the developed countries. Mitral Regurgitation (MR) is a common heart disease which does not cause symptoms until its end stage. Therefore, early diagnosis of the disease is of crucial importance in the treatment process. Echocardiography is a common method of diagnosis in the severity of MR. Hence, a method which is based on echocardiography videos, image processing techniques and artificial intelligence could be helpful for clinicians, especially in borderline cases. In this paper, we introduce novel features to detect micro-patterns of echocardiography images in order to determine the severity of MR. Extensive Local Binary Pattern (ELBP) and Extensive Volume Local Binary Pattern (EVLBP) are presented as image descriptors which include details from different viewpoints of the heart in feature vectors. Support Vector Machine (SVM), Linear Discriminant Analysis (LDA) and Template Matching techniques are used as classifiers to determine the severity of MR based on textural descriptors. The SVM classifier with Extensive Uniform Local Binary Pattern ($ELBP_U$) and Extensive Volume Local Binary Pattern (EVLBP) have the best accuracy with 99.52%, 99.38%, 99.31% and 99.59%, respectively, for the detection of Normal, Mild MR, Moderate MR and Severe MR subjects among echocardiography videos. The proposed method achieves 99.38% sensitivity and 99.63% specificity for the detection of the severity of MR and normal subjects.

1. Introduction

Mitral Regurgitation (MR) is one of the main health concerns and the second most frequent valvular heart disease in the developed countries [1] and so early diagnosis is crucial in the success of the treatment process. MR is defined as an incompetent mitral valve which results in systolic regurgitation of the blood from the left ventricle to the left atrium [2], and is categorized as primary and secondary MR. Exertional dyspnea and decreased exercise tolerance may develop in patients with MR [3]. On the physical examination of patients with MR, loud systolic murmur, third heart sound and early diastolic rumble can be detected. Color Doppler echocardiography is the main method to diagnose MR in patients [4]. The American College of Cardiology/American Heart Association (ACC/AHA) valvular heart disease guideline provides distinct criteria for the classification of chronic primary MR using color Doppler echocardiography; effective regurgitant orifice (ERO), vena contracta (VC), and regurgitant volume [3]. VC is a parameter for determination of the regurgitant orifice. It is the narrowest part of the MR jet at the mitral valve level in views orthogonal to the coaptation line; an apical two-chamber view will falsely increase the VC and in contrast, a parasternal long axis view provides the appropriate view to determine VC.

This technically difficult way of measuring together with the accompanying interpretation is the limitation here. During the calculation of the ERO, it is important to measure the proximal isovelocity surface area (PISA) meticulously, to be accurate enough to determine the severity of MR. PISA radius acquisition is best at the time of peak MR velocity [5].

The ERO is calculated by measuring the PISA radius in the mid-systolic frame of the apical four-chamber view. By using the ERO, the MR severity can be estimated. To obtain the VC, we should measure the smallest width just distal to the regurgitant orifice [4]. The severity of mitral regurgitation is determined according to the latest ACC/AHA guideline for valvular heart disease (mild: $VC < 0.3$; Moderate: $0.3 < VC < 0.7$, $ERO < 0.4$, Regurgitant volume < 60 ml; Severe: $VC > 0.7$, $ERO > 0.4$, Regurgitant volume > 60 ml) [3].

Additionally, cardiac magnetic resonance (CMR) imaging is another useful tool in the diagnosis of the severity of MR, so much

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so that its utility has increased in recent years [6]. Thavendiranathan et al. conducted a systematic review for evaluation, which is a reproducible and accurate tool to quantify the severity of MR. The result showed neither CMR nor 3-dimensional echocardiography or the cardiac CT scan to be superior to other tools [7].

Echocardiography is the most commonly used method in the detection of the severity of MR and so in this paper we use 2D echocardiography for detecting the grades of MR automatically, and in the following sections we briefly explain the echocardiography images and different views which are used in the feature vectors of the proposed method.

Echocardiography is a safe, cost-effective and readily available means of diagnosis in the initial evaluation of heart disease. Cardiac valves and chambers can be evaluated by echocardiography in a non-invasive manner [8]. Transthoracic echocardiograms (TTE) are obtained by placing the transducer on the chest wall to visualize the heart in detail. The apical 4-chamber (A4C) view is found by placing the transducer on the apex of the heart to show a horizontal view of the atrioventricular groove. If the transducer is rotated 90° clockwise, the apical 2-chamber (A2C) view will be visible. The parasternal short axis (PSAX) view, which analyzes the different sections of the heart from base to apex, is captured by rotating the transducer 90 degrees clockwise in the parasternal long axis position [9]. Analysis of the echocardiography images by cardiologists is very important, but echocardiography images are low resolution with artifacts that make the decision difficult. Therefore, computer-aided diagnosis (CAD) is helpful for cardiologists, especially in borderline cases.

Different intelligence techniques have been deployed to improve the diagnosis of heart disease over the years. Various machine learning methods have also been used for the diagnosis of heart diseases: detection of cyclic time series with a hybrid Hidden Markov Model and Support Vector Machine (HMM-SVM) model [10]; a data fusion method to classify heart disease based on a multi-layer feed forward neural network [11]; using a fuzzy-particle swarm optimization (fuzzy-PSO) method for the diagnosis of coronary artery disease (CAD) [12]; using the Growing Time Support Vector Machine (GTSVM) for the separation of innocent and pathological murmurs [13]; and the support vector machine classifier for the diagnosis of ventricular septal defect (VSD) [14] are examples of these researches on heart diseases. Hanbay [15] uses Doppler heart sounds (DHS) data with a Least square Support Vector Machine (LS-SVM) classifier and wavelet packet decomposition (WPD) and Fast Fourier Transform (FFT) as features for the classification of heart valve diseases. The reported accuracy for two normal and abnormal groups which consists of MR subjects is 96.13%. Maglogiannis et al. [16] use DHS data with wavelet decomposition and Short Time Fourier transform (STFT) as features with the SVM classifier for the classification of heart valve disease. The reported accuracy for two normal and abnormal groups is 91.43%, for aortic stenosis (AS) and the MR classification is 91.67% and, for aortic regurgitation (AR) and mitral stenosis (MS) the classification is 93.42%.

Furthermore, to date, there have not been any reports on the automatic diagnosis of the severity of MR. Also, color Doppler echocardiography is a more complex method than 2D echocardiography to implement, and its results are operator dependent [14]. Thus we present a novel method to detect the severity of MR in 2D echocardiography and to classify MR patients from normal subjects with a high degree of accuracy.

Our methodology is represented in Fig. 1. The method uses the novel textural features as training data and three classifiers for finding the correct grade. The rest of the paper is organized as follows. In the next section, we explain the data acquisition method, pre-processing, feature extraction, feature reduction and classification. Section 3 presents the different results of the classification and evaluation parameters. We compare the results with similar previous works in Section 4 and we then conclude the study in Section 5.

2. Methods

2.1. Data acquisition

We enrolled 102 patients categorized in the following cases: mild MR ($n=34$), moderate MR ($n=32$) and severe MR ($n=36$) and we compared these with 37 individuals in the normal group which were collected from the Tehran Heart Center. The normal group was also explained by cases which had neither structural nor valvular heart disease, according to Doppler and color studies, the M-Mode study also showed normal size chambers. They were examined by echocardiography, using the Vivid 7 (GE Medical Systems, Horton, Norway) commercial machine. Comprehensive transthoracic echocardiography was performed with an adjusted setting; the size of the extracted images was 480×640 pixels in DICOM format, the frame rate was 40 fps, the frequency rate 1.7–3 MHz. Echocardiograms were acquired from the standard 2D apical 4-chamber, apical 2-chamber and parasternal short axis views for transthoracic echocardiography. The views were transmitted to a computer and analyzed offline in a blinded manner. All frames had simultaneous electrocardiograms for the determination of cardiac cycles. The severity of mitral regurgitation was evaluated by two well-experienced echocardiographers independently, and graded qualitatively as mild, moderate and severe according to the latest ACC/AHA guidelines for valvular heart disease [3]. If there was any discrepancy among the two gradings, a third investigator's recommendation was used as a reference. We performed transesophageal echocardiography (TEE) as a gold standard for borderline cases according to TTE results which defined the exact category (i.e. mild to moderate MR or moderate to severe MR).

For our experiments, we used 139 independent subjects in the systolic time, with three frames selected from the early, mid and end systolic time, which were synchronized with ECG records. The process was repeated for three views.

2.2. Pre-processing

There are several features of an image, such as image contrast, brightness, size, unessential information, the selection of suitable regions and so on, which affect the robustness and the accuracy of the classification system. Therefore, pre-processing is a crucial step in achieving effective results.

In order to remove noise from the images, a median filter with a 3×3 mask was applied, which also made the image smoother. All images were colored and converted to 8-bit grayscale images. During image acquisition, 480×640 images were taken, which also contained ECG and heart rate (HR). All images were normalized to a resolution of 390×460 and irrelevant details were removed. The result of pre-processing is shown in Fig. 2.

2.3. Feature extraction

The classification relies on features that can describe the differences between groups. Better extracted features in the intelligent methods can lead to better classification results. There are a number of methods to perform the actual feature extraction and typically these methods are divided into categories such as geometrical, statistical, model-based and signal processing [17,18].

In this paper, we propose two novel textural features, ELBP and EVLBP on echocardiography videos which describe the difference of textures between groups.