Identification of Cardiac Cycle Phase in 2-D Echocardiographic Images using Gabor Features Extraction and Artificial Neural Network

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***Abstract*—The heart is a muscular organ that continuously permits circulation of blood throughout the body. The diastolic and systolic phases constitute the cardiac cycle. Diastole is the relaxation state of the heart whereas systole is the contraction state of the heart. It is important to identify the abnormalities in both diastolic and systolic phases so that proper medical treatment can be ensured. This paper presents a novel hybrid method to distinguish the cardiac cycle phases in 2-D echocardiographic images using Gabor features extraction as the initial step in cardiac volume estimation. The artificial neural network is used as the classifier to obtain the anatomical information. Due to the importance of pumping pure blood to the various parts of the body, in this paper the left ventricle is concentrated. The implementation of algorithm is done as computer aided diagnosis (CADi) software. A dataset of 300 echocardiographic images which composed of both normal and infarct cardiac pathologies was taken. The images was denoised using Gaussian noise followed by a tandem of image processing techniques that included Gabor features extraction and edge detection to identify the state of heart muscle for classification by the artificial neural network. This method is greatly helpful in reducing the workload of medical practitioners as it involves automatic detection with better accuracy.**

***Keywords*-Cardiac cycle, echocardiography, gabor features extraction, computer aided diagnosis.**

I. INTRODUCTION

Heart plays an important role in the functioning of the entire body, as it is the organ which pumps oxygenated blood to various parts of the body. The life of a person is therefore directly linked with the heart beat. In recent years, clinical examinations reveal that, the tendency of chronic cardiac failure in humans has increased to great extent and has become a serious problem affecting the health of humans due to various reasons such as blood pressure, cholesterol, obesity [2] etc. Heart is a muscular organ which comprises of four cardiac chambers, the left and right auricles and the left and right ventricles, superior and inferior vena cava, the mitral valve, the aorta, the aortic valve, the tricuspid valve and the pulmonary valve. The cardiac cycle consists of the diastolic phase and the systolic phase. Diastole is the filling of heart chambers with blood and so it can be considered as the relaxation state of the heart muscles. Systole is the pumping of pure blood to the various parts of the body through the blood vessels and so it can be regarded as the period of contraction of the heart ventricles. It is essential to distinguish between diastolic and systolic dysfunctions to proceed with the diagnosis and treatment of patients with cardiac failure. Echocardiography is a method by which the heart and its nearby vessels are visualized with ultrasound waves [3]. Pulses of ultrasound waves are sent from a probe, which is either penetrated or reflected back on a video screen depending on the characteristics of the recorded ultrasound waves. It is a non invasive procedure which yields tremendous amount of hemodynamic information in addition to anatomy. The mitral valve separates the left auricle from the left ventricle and helps in controlling the blood flow through the heart. Due to importance of left ventricle and mitral valve in pumping oxygenated blood, both of these represent a valuable tool for clinically analyzing the cardiac health. Fig.1. presents the structure of the heart.

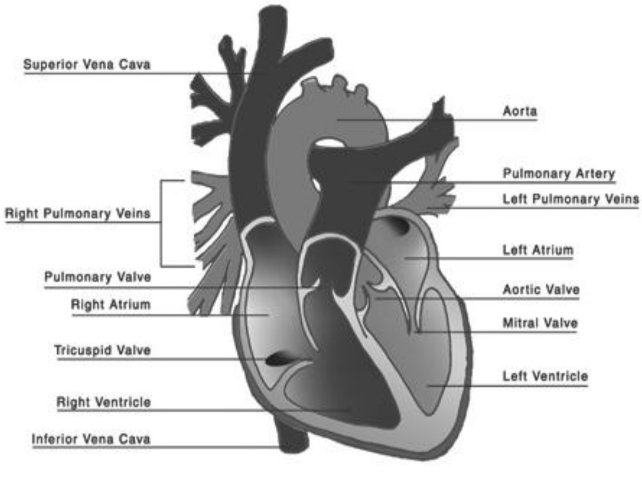

Fig .1. Structure of Heart.

Diastolic heart failure and Systolic heart failure cannot be distinguished by clinical examination whereas the instrumentality of echocardiography helps to solve this problem. Based on the set of image features extracted the echocardiography allows for semi automatic or completely automatic analysis of cardiac phases.

Traditional methods existing today require considerable amount of user intervention for segmentation. This paper presents a new method capable of accurately distinguishing the diastolic and systolic phases in echocardiographic images without involving any manual tracking of boundaries. The image was processed using denoising, binarization and edge detection techniques. The Gaussian noise was used for denoising operation. The image features are extracted using the Gabor features extraction, which possess the optimal localization properties in both frequency domain and spatial domain. Local pieces of information are extracted by Gabor features and are then combined to recognize an object or region of interest. For each image in the dataset, the image features are computed and described by the technique of edge detection. The main aim of this paper is to introduce a new approach with better accuracy which is automatic and helps to reduce the workload of radiologists.

II. METHODS

A. *Experimental Algorithm*

The flowchart of the proposed algorithm is depicted in Fig.2. There are mainly three steps: Image processing, features extraction and Classification. Image can be regarded as an array or matrix of square picture elements (pixels) arranged in rows and columns. Image processing is technique used to convert an image into digital form so as to perform some operations on it to get an enhanced image or to extract some important information from it. In this the image is treated as a 2-D signal while applying a set of signal processing to them. The images are processed using the techniques of denoising, binarization and segmentation. The second step is the features extraction. In this step, a particular region of interest is identified and the image features is extracted using the Gabor features extraction. Instead of concentrating on the mitral valve as in previous works [1], here the features of the entire heart muscles particularly the left ventricle is concentrated. For the extraction of these features the gabor feature extraction is employed. In the third step, the images in the dataset are classified by the instrumentality of Artificial Neural Network by assessing each component of feature vector for both the analyzed cardiac phases. ANN robustly extracts the anatomical information and classifies them into either a healthy diastole, healthy systole, unhealthy diastole or unhealthy systole. It is essential for the advancement of health policies for the diagnosis, control, treatment and prevention of cardiovascular diseases. The dataset consisted of 300 2-D echocardiographic images collected from the hospital in JPEG format. To access the capability of this method to noninvasively gather details of the abnormalities in cardiac phases, frames of cine ultrasound data of the human heart was employed. The gathered images included both normal and abnormal diastolic and systolic cases.

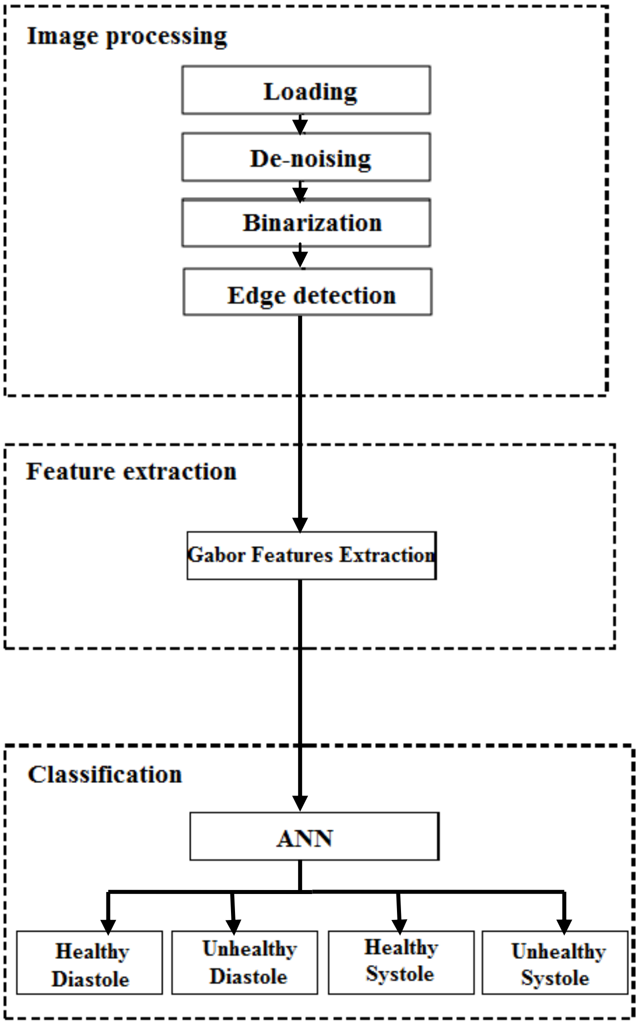

Fig.2. Flowchart of the algorithm.

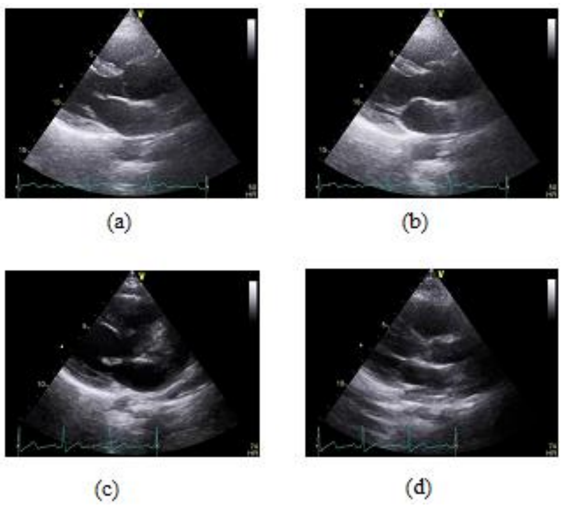

Fig.3. Dataset consisting of : (a) Healthy Diastole (b) Healthy Systole (c) Unhealthy Diastole (d) Unhealthy Systole.

B. Image Denoising

Denoising is the method of reducing the noise content in an image. For echocardiograhic images the efficient and accurate method of noise removal is based on Fourier Transform (FT) and Gaussian low-pass filter (GLPF) [8]. The denoising is achieved in mainly three steps, first is to take the FT. FT translates the image into its frequency components. Secondly, the frequency components are filtered by using GLPF. Gaussian filters have the unique property of being non negative everywhere and also the FT of Gaussian is also a Gaussian itself. Thirdly the inverse fourier transform is calculated to reconvert the image back into spatial domain. The high frequency components are dropped out to achieve smoothing and commonly find application in cases where the algorithms are sensitive to noise (edge detection). Smoothing is used to reduce noise in the images so as to prepare them for further processing such as segmentation and edge detection. The Fourier Transform is calculated by using the following equation:

$$F(u,v) = \sum_{x=0}^{M-1}\sum_{y=0}^{N-1} f(x,y)e^{-i2\pi\left(\frac{u.x}{M}+\frac{v.y}{N}\right)} \qquad (1)$$

where, f(x,y) is the image that is processed,M and N denote the image resolution, F(u,v) is the result of FT.

$$H(u,v) = e^{-\frac{D^2(u,v)}{2D_0^2}} \qquad (2)$$

where, H(u,v) is the transfer function of the GLPF, D(u,v) is tha distance from point (u,v) to center of the filter and D_0 denotes the non negative number associated with the standard deviation. The D_0 parameter determines the quality of denoising process.

$$g(x,y) = \frac{1}{MN}\sum_{u=0}^{M-1}\sum_{v=0}^{N-1} F'(u,v)e^{-i2\pi\left(\frac{u.x}{M}+\frac{v.y}{N}\right)} \qquad (3)$$

where, g(x,y) is the denoised image or the result of inverse FT, F'(u,v) denotes the result of convolution between F and H functions.

Inorder to characterize the quality of the denoising process, noise quality parameters such as mean squared error (MSE),signal to noise ratio (SNR), mean absolute error (MAE) [8] and peak signal to noise ratio (PSNR) are calculated. Higher the values of SNR and PSNR and lower the values of MSE and MAE, better is the denoising process.

C. Binarization Techniques

Binarization is a pre-processing step. This step is used for the conversion of gray image into a binary image. The MATLAB function "graythresh" was used for calculating the default threshold value for binarization. For this the image was first converted from a rgb image to a gray scale image.

D. Image Segmentation and Edge Detection

Segmentation is a process by which a digital image is portioned into multiple segments and is commonly used to locate objects and boundaries in images. Here canny edge detection was used to extract the boundary details of the image. Canny detector is regarded as an optimal edge detector. It first eliminates the noise by smoothing and the finds the image gradients to show the region s with higher spatial derivatives. The algorithm then suppresses any pixel that is not at the maximum and then tracks along those regions [4].

E. Gabor features extraction

Gabor features are features constructed from the responses of Gabor filter. In Gabor features extraction, particular object or region of interest is identified by combining local pieces of information extracted since they possess the optimal localization properties in both spatial and frequency domain. The core of Gabor filter based feature extraction is the 2-D Gabor filter function [5]:

$$\begin{aligned}\psi(x,y) &= \frac{f^2}{\pi\gamma\eta}e^{-\left(\frac{f^2}{\gamma^2}x'^2+\frac{f^2}{\eta^2}y'^2\right)}e^{j2\pi f x'}\\ x' &= x\cos\theta + y\sin\theta\\ y' &= -x\sin\theta + y\cos\theta\ .\end{aligned} \qquad (4)$$

where f is the central frequency of the filter, θ is the angle of rotation, γ is the bandwidth (sharpness) along the Gaussian major axis, η is the sharpness along the minor axis. In the given form the aspect ratio of Gaussian is η/γ. In frequency domain the function has the following analytical form:

$$\begin{aligned}\Psi(u,v) &= e^{-\frac{\pi^2}{f^2}\left(\gamma^2(u'-f)^2+\eta^2v'^2\right)}\\ u' &= u\cos\theta + v\sin\theta\\ v' &= -u\sin\theta + v\cos\theta\end{aligned} \qquad (5)$$

The function is a single real valued Gaussian centred at f in the frequency domain. In this paper the Gabor features are constructed from the responses of Gabor filters in (4) and (5) by using multiple filters on several frequencies f_m and orientations θ_m. Frequency represents the scale information [6] and is given by:

$$f_m = k^{-m}f_{max},\quad m = \{0,\ldots,M-1\} \qquad (6)$$

where f_m is the m^{th} frequency and f_0 is the highest frequency desired and k>1 is the frequency scaling factor. The filter orientation is given by:

$$\theta_n = \frac{n2\pi}{N},\quad n = \{0,\ldots,N-1\} \qquad (7)$$

where θ_n is the nth orientation and N is the total number of orientations. Thus by adjusting θ_n several features can be extracted from the image at different orientations. With the help of a classifier the extracted features can be effectively used to detect the abnormalities in cardiac cycle phases.

F. Artificial Neural Network

The ANN is used as the classifier to identify the healthy and unhealthy diastolic and systolic cases from the features extracted. An artificial neuron is an imitation of the structural constituents of brain termed as the 'neurons', which consists of dendrites (inputs), body and axon (output). The feature vector constitute the inputs $x = [x_1\ x_2\ ...\ x_m]^T$ to the multiple input neuron, w = [w1,1 w1,2 ... w1,m] is the weight vector, b is the bias, ∑ is the summation which performs the linear combination of inputs and f is the activation function which produces the scalar output a, as shown in Fig.4.

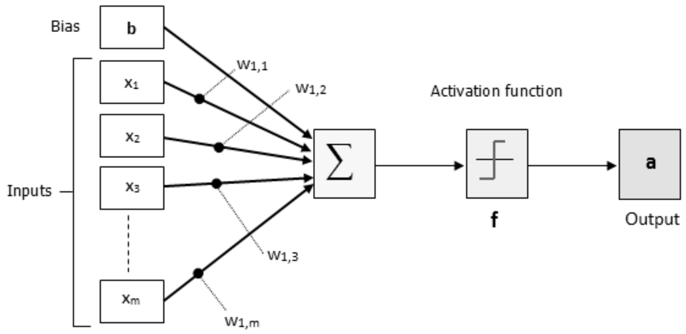

Fig.4. Multiple input neurons.

The neuron output is calculated by

$$a = f(wx + b) \tag{8}$$

G. CADi Application

Inorder to improve efficiency the CADi applications have today become most popular. Making CADi tools as a part of routine clinical work have helped the physicians to detect various diseases thereby reducing the effort required by the radiologists. The efficiency of CADi is computed using the following parameters : sensitivity, specificity, accuracy and precision [7].

$$\text{Sensitivity} = \frac{\text{TP}}{P} \tag{9}$$

$$\text{Specificity} = \frac{\text{TN}}{N} \tag{10}$$

$$\text{Accuracy} = \frac{\text{TP} + \text{TN}}{P + N} \tag{11}$$

$$\text{Precision} = \frac{\text{TP}}{\text{TP} + \text{FP}} \tag{12}$$

where P is the positive condition (diastole) and N is the negative condition (systole), TP is the true positive condition in which diastole is classified as diastole, FN is the false negative condition in which diastole is classified as systole, TN is the true negative condition in which systole is correctly classified as systole and FN is the false negative condition in which the systole is incorrectly diagnosed as diastole.

III. RESULTS AND DISCUSSION

Initially, the dataset set was divided into a set of two: healthy case, which includes both healthy diastole and healthy systole and unhealthy case, which includes both unhealthy diastole and unhealthy systole with the help of a medical practitioner. The output obtained from CADi is as shown in figures:

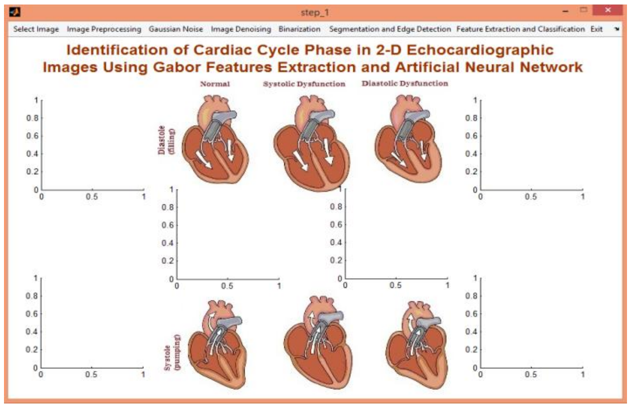

Fig.5. GUI figure file.

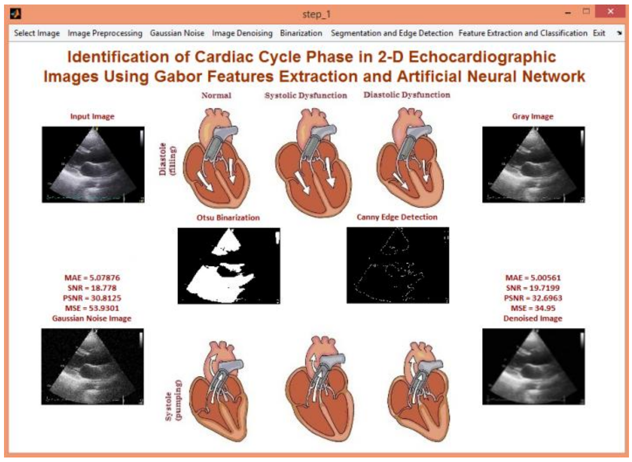

Fig.6. GUI output.

Fig.7. Classification by ANN.

The loaded image was correctly classified as a Healthy Systole. Similarly, all the other echocardiographic images were correctly classified by the artificial neural network employing Gabor features extraction with an accuracy of approximately 93% which is higher than the case when the mitral valve alone was tracked and classified by ANN. Therefore the proposed method helps to classify healthy and unhealthy diastolic and systolic phases in echocardiographic images with better accuracy. Table I shows a comparison of efficiencies between the computer aided diagnosis systems. The Neural Network Toolbox of MATLAB was employed.

TABLE I.

COMPARISON OF CADi EFFICIENCY

Method	*Sensitivity*	*Specificity*	*Accuracy*	*Precision*
ANN	90.7%	89.2%	90%	89.3%
Gabor features extraction and ANN	92.8%	90.3%	92.7%	91.9%

IV. CONCLUSION

A Computer Aided Diagnosis (CADi) method for Cardiac Cycle phase identification in 2-D echocardiographic Images is presented. The previous method was based on Artificial Neural Network alone which produced an accuracy of 90%, however this method is based on ANN classification employing Gabor features extraction in the features extraction stage thereby producing an accuracy of approximately 93%. Thus, in the field of remote heart monitoring field a novel approach is introduced, which offers the patients a more individually focused attention thereby improving the quality of life of patients.

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