New Global and Regional Featuresfor Coronary Artery Disease Detection on 2D Echocardiography

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Abstract

A computer-based of cardiac diagnosis system is needed to assist a cardiologist to evaluate the coronary artery disease quantitatively. In this paper, a computer-based global and regional diagnosis is developed to identify cardiac abnormality on 2D echocardiography. The system consists endocardium tracking, boundary modeling and segmentation, and disease detection globally and regionally.A global index was proposed to predict the left ventricular function by analyzing the shape deformation. Parameters of boundary motion such as displacement, velocity, and strain rate were applied to produce local features of each segment. Fifty-four set data was used to assess the performance of the developed system. Manual interpretation from three experts was used to validate the proposed technique. The results are very promising in recognizing the LV function globally and indicating the abnormality of each segment quantitatively.

1. Introduction

The coronary artery disease (CAD) – the most cardiovascular disease is diagnosed by the cardiologist visually. The heart motion that associated with the function of the cardiac is important information to recognize the problem [1]–[3]. In recent year, the computer-based detection system has been an attracted research to extract deep information associated with the cardiac abnormality [4]–[6]. The systems detect the abnormality of the cardiac function in two approaches: global and regional.

Global diagnosing of the abnormality is performed by analyzing the left ventricular (LV) shape, volume, ejection fraction [7], [8]. In this case, the expert could perform the measurement of the geometry of the LV in apical 2 and 4 chambers only. The regional diagnosing is morecomplicate than the previous one. In this case, the function of each cardiac segment is extracted from all of theechocardiography views. The boundary segmentation of the LV is clearly described in [9].

Currently, many researchers focus to create a system that could help and assist a cardiologist in diagnosing the CAD[6], [10], [11]. There is some weakness that could be improved to increase performance of the disease detection system. In this paper, we also implemented a new technique to medical imaging problem. The methodinvolves motion estimation, boundary modeling and segmentation and disease interpretation.A global index was proposed to assess the left ventricular function by analyzing the shape deformation. Parameters of boundary motion such as displacement, velocity, and strain rate were applied to produce local features of each segment.

2. Methodology

Commonly, the proposed system is described in Figure 1 that consist three parts namely endocardium tracking, boundary modeling and segmentation and disease analysis. Input of the system is a set of 2D Echocardiography in DICOM standard. It includes sequence images, patient record and acquisition information such frame rate, view, recording time and deep of theultrasound signal.

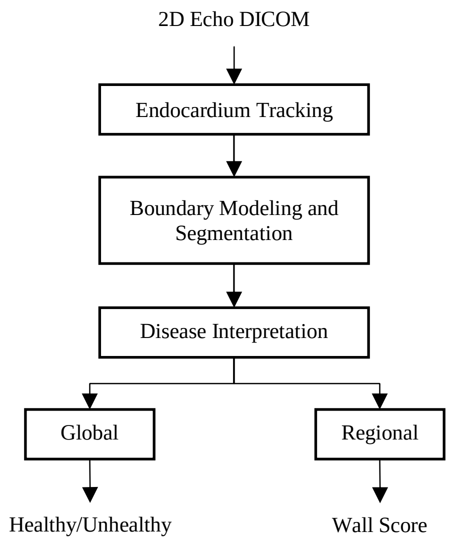

Figure 1. Block Diagram of Computer-based Global and Regional Diagnosis of Cardiac Abnormality on 2D Echocardiography

2.1. Endocardium Tracking

The goal of endocardium tracking is to predict the location of points along the endocardium at each frame if the original points is known exactly. Let $X_o(x,y)$ be an initial point, the position of point at frame *t* can be computed as

$$X_t = X_o + \begin{bmatrix} u \\ v \end{bmatrix}_t \quad (1)$$

The term u and v are horizontal and vertical displacement of the point at frame *t*, respectively. In this case, the movie is started from end-diastole and finished at end-systole of thecardiac cycle.

An optical flow method was applied to estimate the displacement of thepoints between consecutive echocardiography images. The issue of speckle noise in echocardiography image had been solved in our previous study[12]. Combination of wavelet and warping technique in multivariate image could reduce the error due to random noise effect in theultrasound image.

2.2. Boundary modeling and segmentation

Before interpreting the LV function, the model of tracked point wasdeveloped to represent a LV shape. In this case, four shapes that extracted from four views were used to diagnose the CAD.

Let $X_{view}^{1-n}(x,y)$ be a set of points along the endocardium in a view of echocardiography where *n*denotesthenumber of points. In this research, the endocardium boundary is approached by 10 point of each segment. Thus, the LV of each view could be represented using following model

$$f : X_{A2C}^{1-n}(x,y) \Rightarrow \Omega_{A2C}(x,y)_1^{60} \quad (2)$$

$$f : X_{A4C}^{1-n}(x,y) \Rightarrow \Omega_{A4C}(x,y)_1^{60} \quad (3)$$

$$f : X_{PLAX}^{1-n}(x,y) \Rightarrow \Omega_{PLAX}(x,y)_1^{40} \quad (4)$$

$$f : X_{PSAX}^{1-n}(x,y) \Rightarrow \Omega_{PSAX}(x,y)_1^{60} \quad (5)$$

B-Spline de boor was used to interpolate *n* points to 60 points in A2C, A4C, PSAX and 40 points in PLAX. The points were arranged in equiangular distance from the center of the LV chamber. The constructed shape is then used to diagnose the LV function globally and locally.

2.3. Global Feature

In this research, the geometric approach of shape was applied to diagnose the LV function globally. An index of the LV shape is intended to represent the function of systolic contraction. This is accordance with facts that there is some close correlation between shape and cardiac disease especially in CAD [13]. Therefore, a new global feature was proposed to assess the deformation of the LV shape as follow

$$Q = \begin{bmatrix} Q_{A2C}^{ED} & Q_{A2C}^{ES} \\ Q_{A4C}^{ED} & Q_{A4C}^{ES} \end{bmatrix} \quad (6)$$

where each index could be computed as follow

$$Q_{view}^{t} = \frac{4\pi . AP_t^2}{LA_t . SA_t} \quad (7)$$

The term *t* denotes the time in cardiac sequence; ED is for end diastole and ES is for end systole.

2.4. Regional Feature

Regional diagnosing was performed by measuring the physical condition of each segment of theleft ventricle. In this study, a multivariate that combination of the local feature of displacement, velocity and strain rate was usedto evaluate the function of each segment.

$$\Gamma_k^{local} = \frac{1}{n}\sum_{i=1}^{n}\left\{\Gamma_k^i\right\} \quad (8)$$

where Γ_k^i is multivariate feature, *k* denotes the index of the segment and *n*denotes the number of point in each segment.

The multivariate feature of each segment can be formulated as

$$\Gamma_k = \begin{bmatrix} X_x & X_y \\ V_x & V_y \\ SR_x & SR_y \end{bmatrix} \quad (9)$$

where*X*, *V*, and *SR*denote displacement, velocity and strain rate of the segment, respectively. The term x and y denote the horizontal and vertical direction of each feature.

2.5. Disease Diagnosing

A linear discriminant analysis(LDA) was applied to distinguish the disease form the healthy case, which a simple algorithm for supervised feature classification[14]. The proposed global index as mention in equation (6) was used as feature input of the LDA. Some training data was performed to find the LDA parameter.The threshold value of the index was also calculated to distinguish the abnormal LVI index from thenormal case. An unknown data will be predicted as unhealthy case if the LVI index below than the normal threshold.

A sigmoid model was performed to develop a distribution of multivariate of local feature. The output of the model range between 1 and 0 which correspond to normal and abnormal. The values are calculated using sigmoid transfer function as follow

$$Sig(\Gamma) = \begin{cases} \dfrac{1}{1+e^{-\frac{1}{2}\left(\frac{\Gamma-\mu}{\sigma}\right)^2}} & \mu \geq 0 \\ 1-\dfrac{1}{1+e^{-\frac{1}{2}\left(\frac{\Gamma-\mu}{\sigma}\right)^2}} & \mu < 0 \end{cases} \quad (10)$$

where μ and σ denote mean and standard deviation of data distribution respectively.

The result of segmental diagnosis will be shown as Bull's eye plot that following the wall score standard. In this paper, color grading score is intended to distinguish abnormal disease from thenormal case. A green to red grading color was chosen to represent the condition from normal to abnormal.

2.6. Software and GUI Development

All algorithm was implemented using Matlab to create a standalone application and graphical user interface (GUI). Input of the system is DICOM file that not only contain the image but also the patient information. The processing data and the result could be save in Matlab data format for further study.

The software was developed to be used by cardiologist as a second opinion or screening process in diagnosing the abnormality of the LV function. The display of thediagnosis result had been followed the standard of the International Heart Association [9].

3. Data and Experiment

The 2D Echocardiography Data was obtained from themedical database at Cardiac Care Unit UKMMedical Centre with the cardiologist permission. The movie recorded using AcusonSquoia C512 UltrasoundMachine. All data includes four viewsof human cardiac. In this case, a set of echo movie consist 8-11 frames that start from end diastole to end systole. DICOM medical image format was used in image recording due to issue in physical information of the original data such as pixel to meter conversion.

Fifty-four of data were classified by three independent expert as thirty normal subjects and twenty-four abnormal cases with the cardiac ischemic diseases. Advanced diagnosis of LV abnormality interpretation of each data was also performed to strengthen the detailed fact in thespecific case.

Statistical methodhas been used to evaluate the performance of the proposed method such as box plot analysis. A simple classifier was used to assess the performance in discriminating the diseases.

4. Result and Discussion

Figure 2 shows the GUI of the global and regional diagnosing system that developed in this research. The top left part contains the main menu to navigate the function of the software. The main left shows four views of echocardiography image in several types: ultrasound image, boundary tracking, optical flow, compass diagram of segmental movement. The right top part shows the patient information and geometric measurement of LV chamber such volume and ejection fraction. The middle right area is the global diagnosis result and also deformation index ration. The bottom right part is wall scoring result of all LV segment.

Result of global feature for both case, normal and abnormal, is shown in Figure 3. The index value is calculated using Equation (6), whereas the disease status is determined by expert. The box plot shows the proposed feature could separate normal and abnormal data well. Just some outlier data is overlap on normal and abnormal data. The classification accuracy of themethod is 88% using a ten-fold configuration in the experiment using all data.

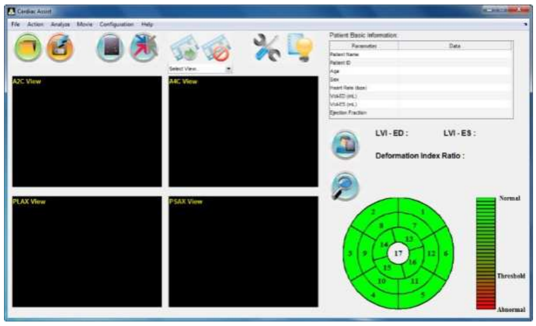

Figure 2. Graphical user interface for diagnosing cardiac disease

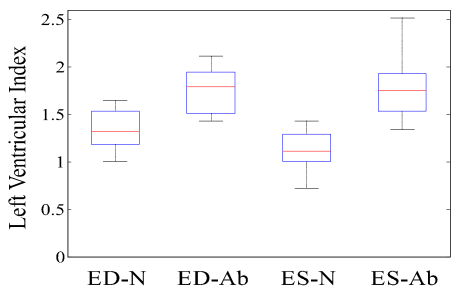

Figure 3. Box plot analysis of left ventricular index at End Diastole (ED) and End Systole (ES) using Normal (N) and Abnormal (Ab) data

A feed forward neural network was chosen to estimate the performance of local feature in detecting the disease of all segments.A Levenberg-Marquardt algorithm was used to train the neural network with 10 neuron at single hidden layer. Dimension of NN input equal with the local feature vector whereas the output is two: normal and abnormal. The classification accuracy of themethod is 83% using a ten-fold configuration in the experiment using all data.

One normal and one abnormal data were chosen to see the performance of the application in diagnosing the CAD. The computation result of both data using proposed system is shown in Figure 4 and 5. Manualinterpretationof the data had been performed by expert.

The first data has been diagnosed by expert and classified as normal. The ejection fraction and the left ventricular index are calculated an amount 53% and 1.4 to 1.2. Both values are above of the normal threshold. In manual regional diagnosis, the expert did not found any abnormality segment except in septal segment. In computed-based diagnosing, the evaluation of all segment is more scalable. As shown in Figure 4, all segments are recognized as normal segment except in base posterior (5), mid anterior septal (8) and mid lateral (12) segment. In conclusion, the computer-based result is almost proper with the expert.

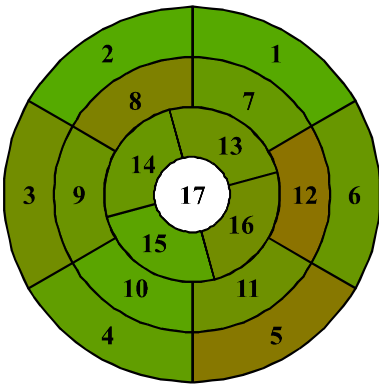

Figure 4. Sample wall score result of local diagnosis using normal data

The second data has been diagnosed by expert as hypokinetic which almost all affected segments move slowly and thicken less than healthy. The ejection fraction and the left ventricular index are calculated an amount 5% and 1.9 to 1.7. Both values are below of the normal threshold. As shown in Figure 5, computed-based diagnosing system found all segments are abnormal since majority the color is red.

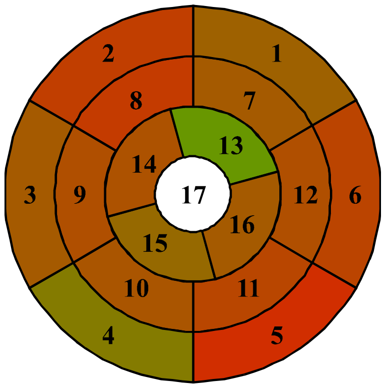

Figure 5. Sample wall score result of local diagnosis using abnormal data

Miscalculation is found in apical anterior (13) that caused by the quality of the endocardium border in theapical area is very poor.

5. Conclusion

We have developed a system to diagnose the coronary artery disease using new global and regional features. 1The system consists endocardium tracking, boundary modeling and segmentation, and disease analysis. Aglobal index was proposed to assess the deformation of the LV shapewithout considering details of thelocation of segments. A local feature was also proposed to locate the abnormal segment. This feature combines three parameter: displacement, velocity and strain rate.

The system was implemented using Matlab to create an application including the graphical user interface. Input of the application is a DICOM file that is a standard file for medical use. Display of regional analysis followed the standard of AHA that using wall scoring method.

Fifty-four set data was used to assess the performance of the developed system. Manual interpretation from three experts was used to validate the proposed technique. The classification accuracy of theglobal feature is 88% using a ten-fold configuration in the experiment using all data. Whereas the average accuracy of the local feature in all segments is 83% using afeed forward NN.

Acknowledgments

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