An Application of Data Mining in Detection of Myocardial Ischemia utilizing pre- and post-Stress Echo Images

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Abstract:

Automatic identification of endocardial and epicardial boundaries of LV has been a focus of research attention in the development of computational methods and computer support for cardiologists in identifying clinical heart disease and their diagnosis. Among heart imaging techniques, echocardiography offers significant advantages because of its low cost, portability, minimal discomfort, the absence of ionizing radiation, and its possible application for patient monitoring through real time processing. However, images generated from echocardiogram data are of poor quality. This paper presents the initial work in the development of a data mining approach for computer-assisted detection of myocardial ischemia, which includes Left Ventricle (LV) wall boundary identification, segmentation and further comparative analysis of wall segments in pre- and post stress echocardiograms.

Keywords: Echocardiograms, Image processing, Multimedia Data mining, Object identification, Ischemia

1. Introduction

The main objective of many efforts in cardiac imaging and image analysis is to access the regional function of the Left Ventricle (LV) of the heart. The general consensus is that the analysis of heart wall deformation provides quantitative estimates of the location and extent of Ischemic Myocardial Injury (IMI) [10]. Regional LV deformation can be determined using all of the principal imaging modalities, including contrast angiography, echocardiography, radio nuclide imaging, cine computed tomography (CT) and magnetic resonance (MR) imaging. Automatic identification of endocardial and epicardial boundaries of LV has been a focus of research attention in the development of computational methods and computer support for cardiologists in identifying clinical heart disease and their diagnosis.

Echocardiography offers significant advantages over all other imaging techniques. The technique is attractive because of its low cost, portability, minimal discomfort, the absence of ionizing radiation, and its possible application for patient monitoring through real time processing [6, 11]. From a data mining point of view, data collected by echocardiograph systems includes sequence data of the heart behaviour.

Myocardial ischemia is a heart disease induced by the obstruction of one or more coronary artery. LV is affected accordingly, which present the change of contractibility of certain segments of LV in echocardiograms images but very rarely on the whole ventricle. The abnormalities can be detected by detailed examination of the dynamics of each segment of LV walls and the coordination between them.

Echocardiography is versatile; it may be combined with exercise, pharmacological, and other stressors and used in availability of circumstances less favorable to other techniques. The stress echocardiography provides a means of identifying myocardial ischemia by detection of stress-induced wall motion abnormalities by comparison of pre- and post stress images. The accuracy of stress echo cardiology in detecting significant coronary stenoses has proved to be from 80% to 90% depending on the population studies [11]. The technological revolution of ultrasound and digital technology brought this modality from a research to a clinical tool, but the interpretation of these studies remains still on subjective observation.

From data mining point of view the echo data can be viewed as video data, which consists of a sequence of echo images, synchronized by the ECG signal. The basic requirement of quantitative analysis of echo images is the complete determination of inner (endocardial) and outer (epicardial) boundaries of the LV wall. In computer vision terms the finding of LV wall boundaries in echo images is an object detection problem. An object detection process typically involves image-processing algorithms for information extraction from images and further analysis of extracted information using priori knowledge of problem domain. A typical configuration of LV wall detection system is shown in Figure 1 [3]:

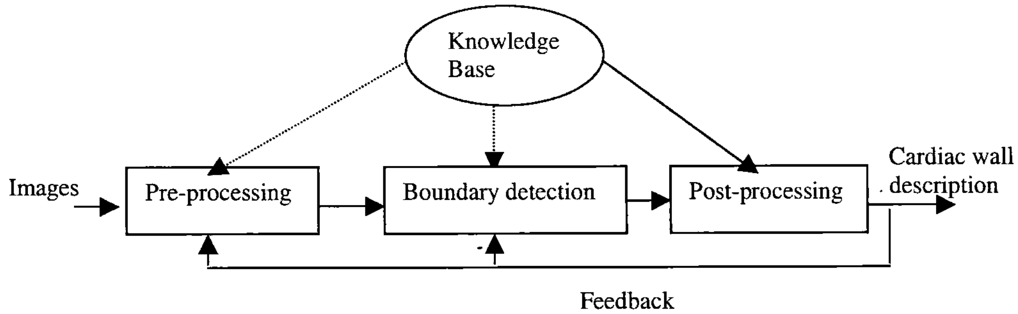


Figure 1. Typical configuration of an LV wall detection system

Algorithms that detect spatial features such as intensity edges [7] and those that detect temporal events such as image motion can provide information for the extraction of LV wall boundaries. Attributes of detected features and events are also useful in interpretation processes. A control strategy manipulates the output from the image processing algorithms to determine the boundary location. An example of the operation taken by the control strategy is the classification of each detected image edge segment as either part of the inner LV wall (endocardial boundary), part of the papillary muscle, part of outer LV wall (epicardial boundary), or an artifact due to noise.

Further, the paper discusses the background of the assessment of regional wall motion abnormalities, the data preprocessing and analysis techniques, the interpretation of the output and further work in the project

2. Assessment of Regional Wall Motion Abnormalities

The American Society of Echocardiography has recommended the use of 16 segment model of LV for assessment of wall motion abnormalities and grading the severity of segmental dysfunction of LV. In 16 segments model, LV is divided into three levels that are further subdivided to produce a total of 16 segments [2]. The three levels such as basal, mid and apical of LV are divided into three equal lengths using the papillary muscles as anatomical landmarks, as shown in Figure 2. The basal and mid levels are divided into six equal segments while the apical level is divided into four equal segments, as shown in Figure 3. The three levels of LV can be captured using parasternal short axis views of the LV in 2-dimensional echocardiography.

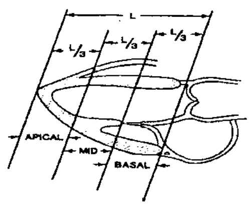
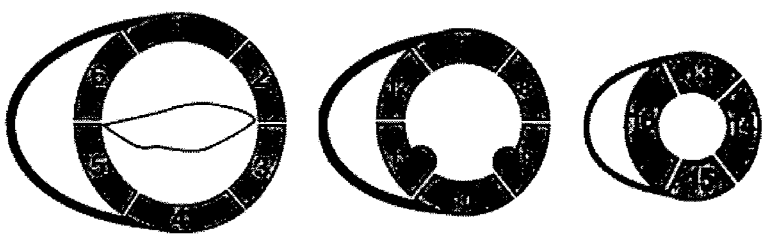


Figure 2. Division of Left Ventricle into Basal, Mid and Apical levels



a. Basal b. Mid c. Apical

Figure 3. Parasternal Short Axis views at Basal, Mid and Apical levels

Recognition of the coronary blood supply to each individual segment of the 16 segment left ventricle aids in the identification of myocardial ischemia. Each myocardial segment can be classified by three coronary artery distributions (anterior, inferior and lateral). The obstruction of one or more coronary artery presents the change of contractibility of certain segments of LV in echocardiography images. The contractility of a segment can be correlated with the level and severity of obstruction or narrowing of relevant coronary artery. Coronary artery distribution to the 16 segment model of the LV is given in Table 1 [2]:

The normal response of the LV to stress is a uniform increase of regional wall motion, thickening and a reduction in end-systolic LV cavity size, with minimal changes in diastolic size[10]. The distinction between resting and stress induced regional wall motion abnormalities fundamentally differentiates prior myocardial infarction (MI), identified by resting akinesis (systolic increase in free wall thickness is less than normal) or dyskinesis (outward movement of wall during systole with associated systolic wall thinning) from induced ischemia, characterized by either new or worsening wall motion abnormalities.

Level	Segment No.	Segment Name	Coronary arteries and Branches
BASAL	1	Anterior	LAD
	2	Anterolateral	LAD
	3	Inferolateral	CF or OM
	4	Inferior	RC or RM
	5	Inferoseptal	RC or RM
	6	Anteroseptal	LAD
MID	7	Anterior	LAD
	8	Anterolateral	LAD
	9	Inferolateral	CF or OM
	10	Inferior	RC or RM
	11	Inferoseptal	RC or RM
	12	Anteroseptal	LAD
APICAL	13	Anterior	LAD
	14	Lateral	LAD
	15	Inferior	LAD
	16	Septal	LAD

Table 1. 16 Segment Model of LV and Coronary Artery supply to each segment.
Where LAD = left anterior descending; CF = circumflex; OM = obtuse marginal; RC = right coronary and RM = right marginal.

4. Data analysis technique

Detection of myocardial ischemia is mainly based on the quantitative analysis of the thickness of ventricle's walls in different stages of the heart cycle. The process of detection can be split into two parts – the identification of the wall boundaries, their approximation and segmentation; and the estimation of quantitative indicators based on dynamic behaviour of the segments of the LV wall in different stages of the heart cycle.

The quantitative analysis of pre- and post stress sequences of echo images are based on the identification of the complete inner (endocardial) and outer (epicardial) boundaries of the LV wall. The poor quality of the images, due to intrinsic limitation of echo imaging such as speckle noise, image drop outs, boundary discontinuity, and disturbances in the images by valves, papillary muscles, etc., makes difficult the automatic boundary identification in echocardiograms. High noise levels are also present due to other artefacts like translation and rotation of imaging object. These noisy effects plaguing 2D data raise real troubles to any computer based feature extraction [3]. Some of the major problems are illustrated in Figure 4. As a result of the clustering threshold a typical boundary detection algorithm will produce, in the context of ventricle wall identification a number of regions that need further steps for identification and approximation of the wall boundaries:

- Closed contours on the ventricle wall – such regions require aggregation into a larger cluster
- Closed contours inside the ventricle – for the analysis of such regions do not belong to the wall in consideration and have to be filtered
- Parts of the wall that are not detected, i.e. contours that include part of the wall as an internal part of the cluster

- Parts of the wall that are identified as boundaries of the ventricle, but are not separated from the rest.

As illustrated in Figure 4, due to the limitations of current echo imaging technology the straight forward application of bitmap clustering and contour detection algorithms may identify only parts of the ventricle wall. Hence, the proposed object extraction technique in echocardiogram images includes the following stages:

- Image data pre-processing and cleaning
- Contour detection and segment computation

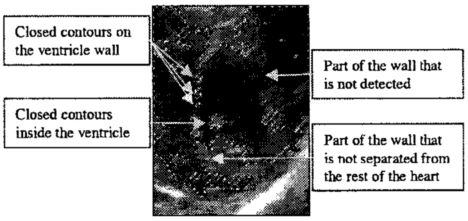


Figure 4. Issues in the identification of ventricle boundaries in echocardiographic images

Image pre-processing

Echo images have very poor signal-to-noise ratio because of the above-mentioned limitations of echo imaging. Pre-processing is required to reduce noise level and to make homogeneous regions uniform. Image pre-processing includes adjusting of colour (in the case of echo images - grey-scale) balances and tonal corrections by adjusting the values of the highlight and shadow pixels in the image, setting an overall tonal range that allows for the sharpest detail possible throughout the image (in extreme cases this can be a black/white separation with respect to a particular threshold, as illustrated in Figure 5, where the threshold for the clusters is computed on the basis of the grey values of the pixels in the corresponding cluster).

There are several implementations of filters but mathematical morphology [7] using opening and closing concepts proved to be more effective technique for emphasizing the epicardial and endocardial boundaries of LV walls in end systolic and end diastolic frames of pre- and post stress echocardiograms.

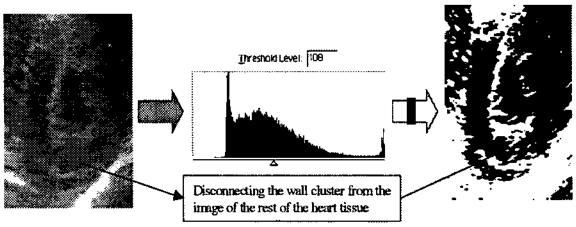


Figure 5. Example of simple image pre-processing step that facilitates the contour detection.

After filtering, the first step is to find the coordinate centre in interior of the cavity where wall contours are being searched. Further the images are converted from Cartesian coordinate system to polar coordinates. Once an image is converted to polar form the so called distance function is found, by defining some special characteristic (first maximum, maximum value, etc.) for each radius and drawing the resulting function [9]. A different distance function is evaluated for each contour. The starting function for inner contour (endocardium) where maximum value of each radius has been used to define the distance function. The goal of the algorithm is to find the best possible functions for both the inner and outer contours from these starting distance functions.

Contour Detection and Segment Computation

Several approaches for detection of LV boundaries in 2D echocardiographs have been reported such as optical flow[9], snakes[4], simulated annealing[5], dynamic programming[8] and possibly others, but unfortunately none of them are effectively applicable to real application due to their respective inherent complexity and applicability problems. Nevertheless these techniques in echocardiogram images suffer mainly from usual poor quality of images. Also they are computationally intensive [6].

The algorithm used in this paper combines the detection of endocardial and epicardial boundaries, and the computation of the area of a segment of LV wall. It is based on a modified form of two-phase relaxation active contour detection technique [1]. The algorithm for detection of contours and computation of area of segmental wall of LV has the following steps:

1. Detection of initial points on epicardial and endocardial boundaries in the image using two different threshold values.
2. Closing the contour using active contours.
3. Dividing the area covered under epicardial and endocardial boundaries in to equal six or four segments depending on the level of image view (e.g. six segments in basal level image of LV).
4. Computation of pixels covered in one segment.

As a result of this algorithm we can approximate the area of a segment of LV wall, which can be further used for 2D or 3D modelling of the LV.

Object analysis, evaluation of the LV condition and interpretation of results

The area value of a segment in an end systolic image and in an end diastolic image of pre- and post stress (peak) echocardiograms are most important for monitoring LV wall motion. The effective change of LV wall from rest to stress echo is uniform at all segments. These measurements have obvious medical importance in detection of ischemic effect of heart. The detection algorithm has been explained as follows:

Let Contractility of segments of LV wall be $C = \{ES, ED, S_n, A_{sn}, A_{dn}\}$, where ES indicates an "End Systolic" image; ED indicates an "End Diastolic" image; S_n is number of segments of epicardial boundary (either 4 or 6); A_{sn} is the area covered between the epicardial and endocardial boundaries in N-th segment in the "End Systolic" image; A_{dn} is area covered between the epicardial and endocardial boundaries in N-th segment in the "End Diastolic" image. C can be expressed as $C = |A_{sn} - A_{nd}|$. Let C_m and C_{on} be the contractility of segment n in pre (r) and post (o) stress images respectively. Then the variance in contractility Δ of segment N is expressed as follows:

$\Delta_n = C_{on} - C_{rn}$

If Δ_n is zero then segment N may have ischemic affect. If Δ_n is negative then segment N may have ischemic affect and requires further comparison between Δ_n and Δ_m, where $m \in (S_n - n), m \neq n$ to evaluate the scale of damage of a segment. If Δ_n is positive then segment N may be normal but further Δ_n should be compared with Δ_m, where $m \in (S_n - n), m \neq n$ for confirmation. Even if a segment has shown the positive variance of contractility but the contractility of that is less than the other ones the segment may have affect of ischemia.

Change of contractility of segments in stress echo images in comparison to rest echo images should be uniform. A segment may have variation in contractility with reference to other segments due to abnormalities in the LV [2]. Based on the above ratios the segmental wall motion can be classified as follows:

- normal - if normal motion at rest with normal/increased wall motion after stress;
- akinesis - if there is absence of inward motion;
- dyskinesis - if paradoxic wall motion in systole;
- hypokinesis if marked reduction in endocardial motion.

A test can be considered positive if wall motion is other than normal. The quantitative measurements can be correlated with the severity of myocardial infarction of the LV wall, which may be induced by narrowing or obstructions of connected coronary arteries to the segment.

5. Discussion and future work

The paper presents the initial work in the development of a 'smart cardiographer' to assist cardiologists, based on the analysis of echocardiogram images and video sequences. The wall detection algorithms utilise the video sequence data, when the actual analysis is based on the ratios between the wall contours on a specific images ("End Systolic" and "End Diastolic" images). The proposed algorithm provides scope of quantitative analysis of segmental LV function for more accurate clinical diagnosis and management of ischemic affect of heart. Another important perspective of this study is the evaluation of the role of continuous non-invasive monitoring of arterial blood pressure and restriction.

The work on the 'smart cardiographer' includes also the development of media integration model and visual presentation of the results. The media integration is connected with data modelling for multimedia data. The visual presentation of the results involves the analysis of human computer interaction issues related to the medical experts in the area.

References

1. Acharya B, Mukherjee J, and Majumdar AK, "Two-phase relaxation approach for extracting contours from noisy echocardiogram images", in Proc. Int'l Conf. Pattern Recog. and Digital Tech. (ICAPRDT 99), pp 144-148, 1999.
2. Anderson B "The Normal Examination and Echocardiographic Measurements", Edition 1, MGA Graphics, 2000.
3. Chu CH and Delp EJ, "Automatic Interpretation of Echocardiograms – A computer vision Approach", IEEE ISCAS, pp 2611-2614 1988.
4. Cohen LD and Cohen I. "Finite element methods for active contour models and balloons for 2D and 3D images", IEEE Transactions on Pattern Analysis and Machine Intelligence, 15, pp 1131-1147, 1993.
5. Friedland N and Adam D. "Automatic ventricular cavity boundary detection from sequential ultrasound images using simulated annealing", IEEE Transactions on Medical Imaging, 8(4), pp 344-353, 1989
6. Giachetti A. "Online analysis of echocardiographic image sequences", Medical Image Analysis, vol 1, pp 1-25, 1996.
7. Klingler JW Jr., Vaughan CL, Fraker TD and Andrews LT, "Segmentation of Echocardiographic Images Using Mathematical Morphology", IEEE Transactions on Biomedical Engineering, Vol35 No 11, November 1988.
8. Maes L, Bijnens B, Suetens P and Van de Werf F. "Automated contour detection of the letft ventricle in short axis view in 2D echocardiograms", Machine Vision and Applications, 6(1), pp 1-9, 1993.
9. Mailloux G and AB et. al. "Computer analysis of heart motion from 2-dimentional echocardiograms", IEEE Transactions on Biomedical Enginering, 34(5), pp 356, 1987.
10. Marrwich TH, "Stress Echocardiography", in the book "Comprehensive Cardiovascular Medicine, edited by Eric J. Topol, Lippin cott". Lippincott Raven Publication, Philadelphia 1998. pp 1407-1436.
11. Papademetris X, Sinusas AJ, Dione DP and Duncan JS, "Estimation of 3D Left Ventricle Deformation from Echocardiogrpahy", Medical Image Analysis, 5(2001) 12-28.
12. Skorton DJ, Collins S, Garcia E, Geiser EA, Hillard W, Koppeo W, Linker D, and Schwarts G, "Digital signal and image processing in Echocardiography," American Heart Journal, 11(6), pp 1266-1283, 1985.
13. Torres L and Gasull A. "Temporal Automatic Edge Detection of Echocardiographic Images", Proceedings of IEEE Conference on Computers in Cardiology 1990, pp 2149-2152.