Quantitative Detection of Left Ventricular Wall Motion Abnormality by Two-Dimensional Echocardiography

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Abstract

Echocardiography is a widely used imaging technique to examine various cardiac functions, especially to detect the left ventricular wall motion abnormality. Unfortunately the quality of echocardiograph images and complexities of underlying motion captured, makes it difficult for an in-experienced physicians/ radiologist to describe the motion abnormalities in a crisp way, leading to possible errors in diagnosis. In this study, we present a method to analyze left ventricular wall motion, by using optical flow to estimate velocities of the left ventricular wall segments and find relation between these segments motion. The proposed method will be able to present real clinical help to verify the left ventricular wall motion diagnosis.

Keywords: Left ventricular, Echocardiograph, Short axis, Optical flow

1. Introduction

Echocardiogram has become an important diagnostic tool in modern cardiology. Although this imaging modality is the most widely used to evaluate regional left ventricular function, it allows non-invasive real-time visualization of left ventricular motion. Evaluation of the left ventricular function based on subjective experience-dependent visual interpretation of dynamic images of echocardiograph. Unfortunately echocardiograph is notoriously difficult to interpret even for the best physicians where they could misdiagnose the heart disease. Hence there is a tremendous need for an automated technique that can provide objective diagnostic assistance, particularly to the less-experienced cardiologist.

In this study, we address the task of building a computer aided diagnosis system that can detect LV motion abnormalities from echocardiograph. Our work based on the anatomical structure of the left ventricular wall in short axis echocardiograph and we will use the wall thickening as a parameter to evaluate a profile for the regional myocardial function in normal conditions.

The following section provides some medical explanation on the function and anatomy of the left ventricular and explains the standard views of echocardiograph. In section 3 we describe our methodology, which consist three sub-sections: data preparing; velocity estimation and data analysis. We display and describe our experimental results in section 4. Section 5 contains our conclusion and our plans for future work.

2. Medical background

Left ventricular is the most energetic element and plays a central role in the cardiac mechanics as well as in the diagnosis of the heart function. It is one of the four chambers (two atria and two ventricles) of the heart, receives oxygenated blood from the left atrium via the mitral valve and pumps it into the aorta via the aortic valve.

There are many imaging modalities that have been used to measure left ventricular mass, dimension and function such as echocardiography, radionuclide ventriculography, electron beam, Computed tomography (CT) and Magnetic resonance imaging (MRI). For this project we choose to use echocardiography that has the advantage of it is non-invasive, simple and differentiates the cardiac phases. This imaging modality has four standard views: Apical 4 chambers (A4C), apical 2 chambers (A2C), parasternal long axis (PLAX) and parasternal short axis (PSAX). These views results from cutting heart along different 2-D planes.

In this study, we focus only on the short axis view (PSAX) which shown in figure 1. This view showing the left ventricular that provide the mainstay and segmental analysis for most clinical modalities that image the left ventricular. It results in a circular view which can be divided into three segments depending on the major coronary arteries: the left anterior descending (LAD) which feeds segment A, the left circumflex coronary artery (LCX) feeds segment B and the right coronary artery (RCA) feeds segment C.

Left ventricular wall have a nonuniform thickness, this wall thickening nonuniformity is an important parameter of regional function. Whereas when the wall thickness increased results in higher ejection fraction (EF) and higher strains. When we looked around the circumference of the ventricle (figure 2), we notice that there is a difference between the three segments wall thickness, segment A have thin wall, segment B was thicker than segment A and segment C thicker than segment B. The regional function of the left ventricular motion in the three segments is highly characterized by wall thickening.

3. Methodology

3.1 Preparing data

In this work, short-axis view was chosen because it's more representative for the cardiac function than other views and pilanimetry results in nearly circular area. In addition, partial-volume affects are less in short axis view compared to others.

First, we designed a program by using MATLAB for converting echocardiograph video to two dimensional frames. Then detect the region of interest (left ventricular cavity) by specific dimension and divide the region of interest into three segments (A, B and C) by a uniform displacement.

3.2 Computing Velocity Features

To distinguish between the normal and abnormal motion of the three segments, it is necessary to evaluate velocity for each segment. In this work, we evaluate the velocity using popular optical flow called Horn and Shunck [Horn and Scunck, 1981]. The Horn and Schunck algorithm assumes smoothness in the flow over the whole image. Thus, it tries to minimize distortions in flow and prefers solutions which show more smoothness. The flow is formulated as a global energy functional which is then sought to be minimized. This functional is given for two-dimensional image streams as:

$$E = \iint \left[\left(I_x u + I_y v + I_t \right)^2 + \alpha^2 \left(|\nabla u|^2 + |\nabla v|^2 \right) \right] dx dy$$

Where Ix, Iy and It are the derivatives of the image intensity values along the x,y and time dimensions respectively, and parameter α scales the global smoothness term. The Horn and Shunck method minimizes the previous equation to obtain the velocity field [u v] for each pixel in the image, which are given by the following equations:

$$\frac{\partial L}{\partial u} - \frac{\partial}{\partial x}\frac{\partial L}{\partial u_x} - \frac{\partial}{\partial y}\frac{\partial L}{\partial u_y} = 0 \quad (1)$$

$$\frac{\partial L}{\partial v} - \frac{\partial}{\partial x}\frac{\partial L}{\partial v_x} - \frac{\partial}{\partial y}\frac{\partial L}{\partial v_y} = 0$$

Where L is the integrand of the energy expression, giving

$$I_x(I_x u + I_y v + I_t) - \alpha^2 \Delta u = 0 \quad (2)$$

$$I_y(I_x u + I_y v + I_t) - \alpha^2 \Delta v = 0$$

Where $\Delta = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2}$ denotes the Laplace operator

The optical flow use an iterative process to calculate the optical flow between video frames, then the iterative process stop when it reaches a certain number of iterations. The iterative scheme derived as shown in the following equations:

$$u^{k+1} = \bar{u}^k - \frac{I_x(I_x \bar{u}^k + I_y \bar{v}^k + I_t)}{\alpha^2 + I_x^2 + I_y^2} \quad (3)$$

$$u^{k+1} = v^k - \frac{I_y(I_x \bar{u}^k + I_y \bar{v}^k + I_t)}{\alpha^2 + I_x^2 + I_y^2}$$

In this equation, $[u_{xy}^k \; v_{xy}^k]$ is the velocity estimate for the pixel at (x,y), and $[\bar{u}_{xy}^k \; \bar{v}_{xy}^k]$ is the neighborhood average of $[u_{xy}^k \; v_{xy}^k]$ for k=0, the initial velocity is 0.

To get accurate velocity for each segment in one cardiac cycle, we extract the standard deviation of velocities as shown in table 1, where the results suits the previous knowledge of left ventricular anatomy.

3.3 diagnosis decision

To make diagnose decision and detect which segment is abnormal, we involve the extraction and calculation of the three segments motion features by calculate ratios between the three segments. Each ratio is computed by dividing the standard deviation of thin segment velocities with the standard deviation of thicker segment velocity:

$$R1 = \frac{StdVa}{StdVb}$$

$$R2 = \frac{StdVb}{StdVc}$$

$$R3 = \frac{StdVa}{StdVc}$$

When each of the thin segments is divided by thicker segment, it is observed that the ratios for normal motion are closer to 1.0 and in abnormal motion the ratios are higher or equal to 1.0. Table 2 clearly shows the results obtained from ratios calculation of 42 samples. We could conclude that the proposed method is able to classify normal and abnormal motion.

4. Experimental results

All the experiments were performed using MATLAB to demonstrate the effectiveness of our method and characterize the features and limitations of the method. The 2D echocardiograph images obtained for different patients were reviewed and diagnosed by an expert cardiologist, who graded wall motion in each segment (three segments) as normal or abnormal.

The main parameter in our method is the nonuniformity of the left ventricular wall thickness, where thick wall cause more strains and higher ejection fraction EF. The three segments of left ventricular wall have different thickness (segment A < segment B < segment C); corresponding to the imparity of the wall thickness we assume there is imparity in velocities of the three segments. This imparity has a uniform structure in normal motion and any variation from normal could be used to detect abnormal motion.

We test the method on 42 videos and obtain the complete representation of left ventricular motion by comparing the standard deviation of velocities Std for the three segments as shown in table 1. The velocities recorded in one cardiac cycle and only the Std of each segment is used to illustrate the comparison between the three segments. From table 1 we notice that all segments have a uniform structure where thicker wall has higher velocity, this fact suits with the previous anatomical knowledge of the left ventricular. Figures 3(a, b) shows two examples for normal and abnormal motion to clarify the movement structure. The comparison of the three segments movement is not enough to detect which segment is abnormal specifically in some cases not all segments abnormal. For that we calculate the ratios between the segments motion. We found one observation that the ratio of normal motion is closer to 1.0 while abnormal motion have higher ratio as shown in table 2.

Unfortunately, due to the limited nature of past published systems and the difference in segmentation we do not have any numerical results that compare our results with it. To validate our method, we compare our results with expert cardiologist. The recall was computed:

$$recall = \frac{number\ of\ validations}{total\ number\ of\ videos}$$

The recall for our experiments is 71%, as can be seen the method have acceptable recall value. With increase in the number of videos, the recall and precession are expected to increase. Obviously can be seen that the structure we found mirrored the anatomical structure of left ventricular and the proposed method successfully detect the left ventricular motion in echocardiograph images and could reduce the errors in diagnosis.

5. Conclusion

Clinical assessment of the left ventricular wall motion is mostly based on visual inspection which may cause errors in diagnosis especially with in-experienced physicians and low quality of dynamic echocardiograph. Experimental results presented in the previous section showed results and possible limitation of our study to improve diagnostic accuracy. The results of our work looks promising in the ability of motion estimation of the left ventricular, especially the structure that we found using the data actually mirrored the anatomical structure of left ventricular in short-axis view. Furthermore, there is no need to build large dataset with specific parameters about patient (like: age, sex, body weight and body surface area) to get accurate diagnosis. This work could be an important aid to improve and support diagnostic accuracy and to prognostic method for the investigation of diagnosis for the left ventricular diseases.

In the future we plan on expanding our work on other standard echocardiograph views (for example: Apical 4 chambers (A4C), apical 2 chambers (A2C), parasternal long axis (PLAX)). Although we only had a relatively small number of cases, we plan to add more cases in the future to improve the performance.

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Table 1. The standard deviation of velocities for different patients with normal and abnormal LV motion

No.	LAD	LCX	RCA	No.	LAD	LCX	RCA
V1	0.4945	0.5447	0.8526	**V22**	0.4923	0.4163	1.324
V2	0.2831	0.4346	0.8763	**V23**	0.3947	0.3814	0.1488
V3	0.3121	0.4337	0.8517	**V24**	0.4059	0.4733	0.8226
V4	0.2288	0.3121	1.401	**V25**	0.6103	0.8719	0.9814
V5	0.4834	1.093	1.388	**V26**	0.7315	0.4179	1.038
V6	0.6595	0.4548	0.2153	**V27**	0.2991	0.4479	0.8808
V7	0.1337	0.3991	1.04	**V28**	0.2661	0.4946	1.251
V8	0.5831	0.4346	0.2763	**V29**	0.9706	1.482	0.9325
V9	0.1595	0.4548	0.5153	**V30**	0.645	0.749	0.8118
V10	0.1625	0.4529	0.4805	**V31**	0.4581	0.8917	0.441
V11	0.645	0.749	0.8118	**V32**	0.2706	0.482	0.9325
V12	0.4572	0.8917	1.441	**V33**	0.1748	0.5135	0.7899
V13	0.3555	0.6586	0.6857	**V34**	0.553	0.733	1.365
V14	0.3942	1.087	0.8247	**V35**	0.3555	0.6586	0.6857
V15	0.5774	0.3589	0.2502	**V36**	0.6604	0.7038	0.7839
V16	0.6088	0.8595	0.4967	**V37**	0.2973	0.3957	0.5748
V17	0.4403	0.3815	0.414	**V38**	0.3699	0.5948	0.5202
V18	0.6226	0.5695	0.5497	**V39**	0.3677	0.4106	0.9143
V19	0.6088	0.8595	0.4967	**V40**	0.5699	0.7455	0.2745
V20	0.9706	1.482	0.9325	**V41**	0.41	0.454	0.6902
V21	0.4834	1.093	1.388	**V42**	0.7625	0.4529	0.4805

Table 2. The ratios

No.	R1	R2	R3	NO.	R1	R2	R3
V1	0.9078	0.6389	0.5791	**V22**	1.1826	0.3144	0.3718
V2	0.6514	0.4959	0.3231	**V23**	1.0349	2.5632	2.6526
V3	0.7196	0.5092	0.3664	**V24**	0.8576	0.5754	0.4934
V4	0.7331	0.2228	0.1633	**V25**	0.6991	0.8884	0.6219
V5	0.4423	0.7875	0.388	**V26**	1.7504	0.4026	0.7047
V6	1.4501	1.1722	3.0632	**V27**	0.6678	0.5085	0.3396
V7	0.335	0.3838	0.1286	**V28**	0.538	0.3954	0.2127
V8	1.3417	1.5729	2.1104	**V29**	0.6549	1.5893	1.0409
V9	0.3507	0.8826	0.3095	**V30**	0.8611	0.9226	0.7945
V10	0.3588	0.9426	0.3382	**V31**	0.5137	2.0219	1.0388
V11	0.8611	0.9226	0.7945	**V32**	0.5614	0.5169	0.2902
V12	0.5127	0.6188	0.3173	**V33**	0.3404	0.6501	0.2213
V13	0.5398	0.9605	0.5184	**V34**	0.7544	0.5369	0.4051
V14	0.3626	1.3181	0.4771	**V35**	0.5398	0.9605	0.5184
V15	1.6088	1.4345	2.3078	**V36**	0.9383	0.8978	0.8425
V16	0.7083	1.7304	1.2257	**V37**	0.7513	0.6884	0.5172
V17	1.1541	0.9215	1.0635	**V38**	0.6219	1.1434	0.7111
V18	1.0932	1.036	1.1326	**V39**	0.8955	0.4491	0.4022
V19	0.7083	1.7304	1.2257	**V40**	0.7645	2.7158	2.0761
V20	0.6549	1.5893	0.9941	**V41**	0.9031	0.6578	0.594
V21	0.4423	0.7875	0.3483	**V42**	1.6836	0.9426	1.5869

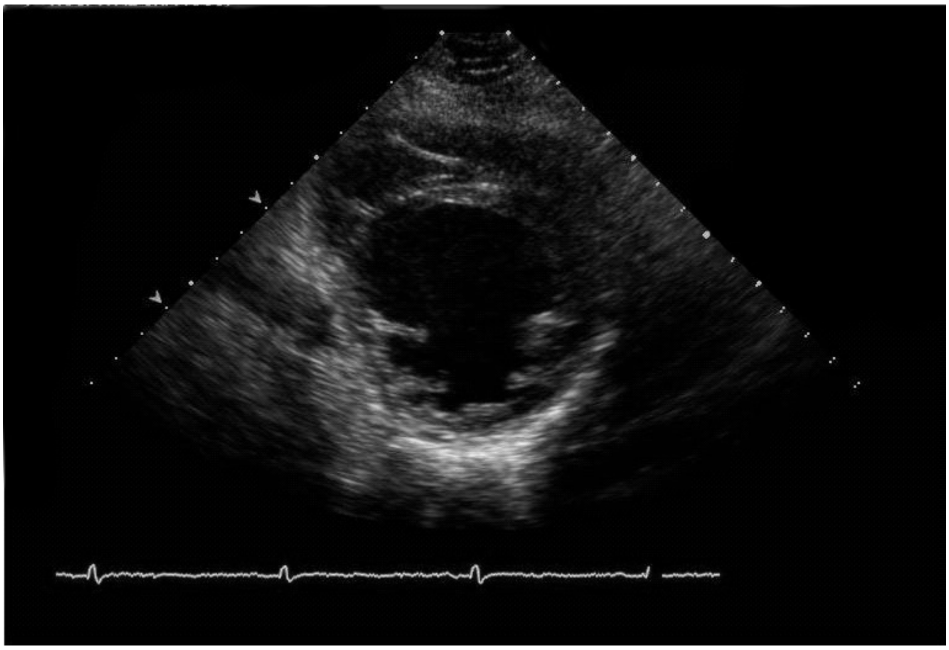


Figure 1. cross sectional view of the left ventricular (LV)

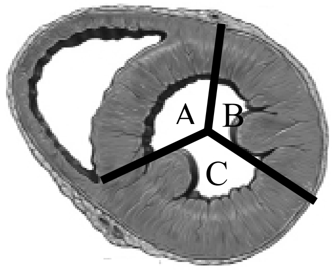
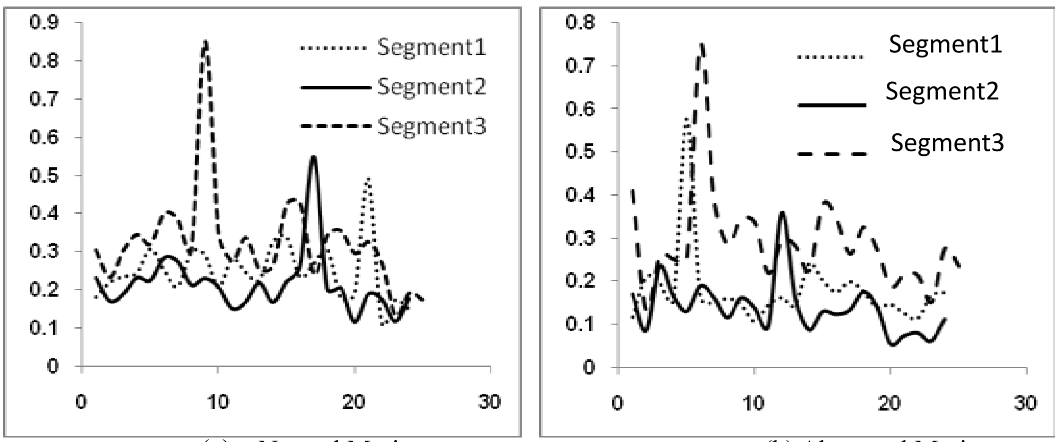


Figure 2. left ventricular cavity, divided into three segments corresponding to the major coronary arteries: (A) feds by the left anterior descending (LAD), (B) feds by the left circumflex coronary artery (LCX), (C) feds by the right coronary artery (RCA).



(a) Normal Motion (b) Abnormal Motion

Figure 3. two examples for different patients, (a) results of standard deviation for normal motion in one cardiac cycle. (b)Standard deviation of abnormal motion where segment B have abnormal motion, it have slower motion where it have thicker wall than segment A.