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Cardio-Spatial Profile Extraction using Optical Flow of Echocardiographic Images

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***Abstract*—Detection of cardiac movement is very important subject on cardiac image analysis. Cardiologist needs an accurate motion estimation to diagnose the abnormality of cardiac. In this paper, we present the utilization of optical flow technique to estimate the myocardial motion. Then the computed motion vectors are used to provide the cardiac profile, such as its displacement and direction. The proposed implementation provides real-time movement profiles of cardiac with a precision up to 0.11 pixel / 22.50° for their displacements / motion orientations.**

***Index Terms*—Optical flow, myocardial movement, cardiac profile, echocardiography.**

I. Introduction

Heart attack occurred when the blood supply to the heart is interrupted (ischemia). Ischemic segment of heart is indicated by the abnormality of myocardial movement. Since the heart attack is a leading cause of deaths over the world, it is crucial to monitor the cardiac condition for early detection of its abnormalities. The study of myocardial movement from 2-D echocardiography has been an active research in past decades. Jacob et al (2002) introduced shape-space-based segmentation to identify myocardial boundaries. This technique obtains inaccurate results due to noisy data in the echocardiography images [2]. Another approach from Kazulinski (2001), detects the movement of myocardial using speckle tracking [3]. The third approach is by using optical flow estimation technique to compute the displacement field of two consecutive images [4][5]. Recently, the last mentioned technique is the most popular approach used in the myocardial motion estimation. Various improvements and modifications have been done by researcher whether in theory or application approach of the optical flow. In this study, we implement the optical flow technique modified by Brox et al [7] on echocardiographic images to generate the cardiac movement profiles. These profiles ease the cardiologist in diagnosing cardio abnormalities.

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II. Division of the Cardiac and its Movement

The Cardiac Imaging Committee of the Council on Clinical Cardiology of the America Heart Association has released a standardized myocardial segmentation and nomenclature for tomography imaging of the heart [2]. It includes four standard views for echocardiographic image collection from patient, i.e. parasternal long axes (PLAX), parasternal short axes (PSAX), apical four chambers (A4C) and apical two chambers (A2C). In this paper, the evaluation of myocardial movement is focused only on the PSAX view as shown in Fig. 1. The left ventricular (LV) appears as a cavity in a center surrounded by six myocardial segments. The normal cardiac appearance is indicated by a uniform displacement of myocardial segments. They move in radial forward and backward directions with respect to the center of cavity, which describe the profile of systole and diastole of a cardiac. In one period of time, the cavity size will shrink progressively during systole. And it is followed by a brief instance of diastole that recovers the cavity [8]. Thus the velocity of each segment is computed accurately during one complete cycle of myocardial movement.

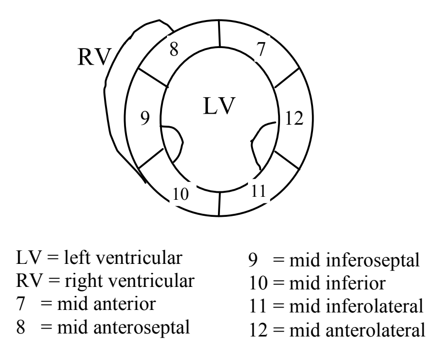


Fig. 1 PSAX view of echocardiography image and its segments

III. Methodology

The methodology involves several tasks such as the collection of echo-cardiographic images, the computation of optical flow field and the extraction of the movement profile. In this work, PSAX view of echocardiographic video is obtained from the patient with healthy cardiac in the rest condition (baseline). Then, the motion vector is represented by the optical flow between two consecutive frames of echocardiographic images. Finally, the movement profile is obtained by averaging the displacement and the orientation of several locations on the myocardial segments respectively.

IV. Optical Flow Computation

Optical flow is a common technique to estimate the displacement field of an object movement. Nevertheless, this area still has many rooms for improvement in the theoretical and application approaches. Optical flow field is computed by assuming that the intensity of the object is remained constant from the initial point of $I(x, y, t)$ towards the latest position of $I(x+\delta x, y+\delta y, t+\delta t)$. Thus, the intensity constraint of a point is represented by:

$$I(x, y, t) = I(x+\delta x, y+\delta y, t+\delta t) \tag{1}$$

Within small value of δx, δy and δt, the intensity constraint can be represented using the 1st order of Taylor series expansion as,

$$I(x+\delta x, y+\delta y, t+\delta t) = I(x,y,t) + \frac{\partial I}{\partial x}\delta x + \frac{\partial I}{\partial y}\delta y + \frac{\partial I}{\partial t}\delta t \tag{2}$$

By simplification of equation (1) and (2), the basic constraint equation of optical flow can be expressed as

$$I_x v_x + I_y v_y + I_t = 0 \text{, or}$$

$$I_x u + I_y v + I_t = 0 \tag{3}$$

The intensity constancy assumption is very sensitive to brightness changes that contrarily often appear in natural cases. Therefore, it is important to introduce small variation of intensities within the initial intensity value itself. This criterion, as known as gradient constancy assumption, is expressed as:

$$\nabla I(x,y,t) = \nabla I(x+u, y+v, t+1) \tag{4}$$

Brox et al [7] summarized that using three assumptions, namely intensity constancy, gradient constancy and smoothness assumption, velocity vectors u and v can be determined by minimizing the total of energy $E(u,v)$, such that:

$$E(u,v) = E_{Data} + \alpha E_{Smooth} \tag{5}$$

where $\alpha > 0$ is the regularization parameter. The derivation of intensity and gradient constancy assumption can be expressed as:

$$E_{Data}(u,v) = \int_{\Omega} \Psi(|I(x+w) - I(x)|^2 + \gamma |\nabla I(x+w) - \nabla I(x)|^2) dx \tag{6}$$

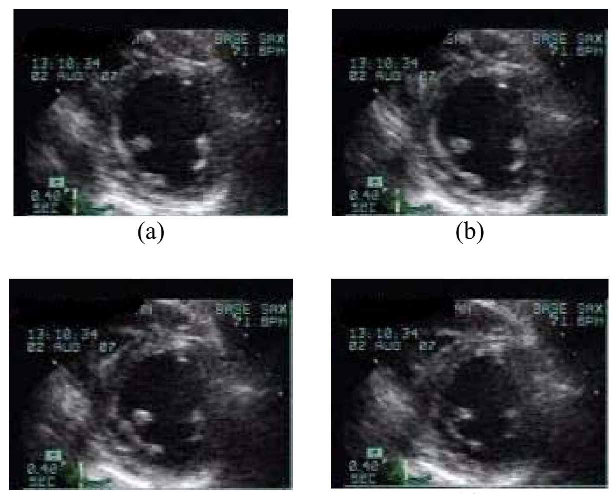
To overcome aperture problem, researchers introduced the smoothness assumption. Optical flow computation is not only based on a single pixel displacement but it also considers the interaction between neighbouring pixels. This smoothness criterion is computed using total variation of the piecewise smooth flow field which can be expressed as:

$$E_{Smooth}(u,v) = \int_{\Omega} \Psi(|\nabla_3 u|^2 + |\nabla_3 v|^2) dx \tag{7}$$

V. Result and Discussion

A. Velocity vector of myocardial movement

The above summarized procedure of optical flow computation will be used for myocardial motion estimation to generate its movement profile. Fig. 2 shows the sequences of myocardial movement where Fig. 2(a) to (d) indicates the diminishing motion of LV. The computed vectors of myocardial movement between two consecutive images are shown in Fig 4. These arrows represent the displacement of the pixels and their directions. The different colours of arrows represent the speed of displacements that change gradually from red to blue colour indicating large to small displacement representation. In this study, the direction of vector flow is fixed as in Fig. 3. Thus, if the pixel moved from right to left, then the direction would be approximately 180^0. In Fig 4, the movement of myocardial is represented by red arrows of the optical flow. These arrows diminish towards the centre of cavity during systole state.



(a) (b) (c) (d)

Fig. 2 Four sequences of myocardial movement from clinical echocardiography images; the LV appears in the centre of cavity and diminish from (a) to (d)

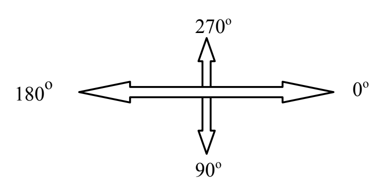
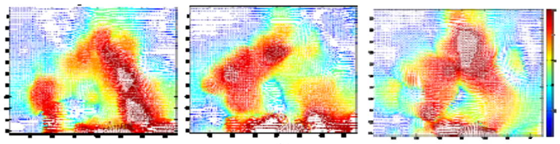


Fig. 3 The direction of movement used.



(a) (b) (c)

Fig. 4 Computed velocity vector between two sequence images; (a) frame-1 to frame-2, (b) frame-2 to frame-3 and (c) frame-3 to frame-4

B. Cardiac profile extraction

Several points at each myocardial segment are selected in order to provide the profiles of myocardial movement. Five points are used at every segment as shown in first column of Fig. 5, from (a) to (f), for segment 7 to 12. For each segment, the displacement profile and direction profile are computed by averaging the profiles of five selected points which is depicted in the second and third column of Fig. 5.

The segment 7 of Fig. 5(a) moves with a relative constant displacement of each frame. The directions of each movement have value from 90^0 to 180^0 which agree with the real movement of segment 7, i.e. from right to left-down direction. The same fact also can be seen on the movement of segment 9 which moves from left to right-up during systole (Fig. 5(c)). The computed direction profile has value from 270^0 to 360^0 indicated the right direction of this segment. However, some computed values do not follow the trend of movement due to the wrong optical flow computation. In summary, the computed myocardial profile can accurately represent the movement of each segment with 0.11 pixels and 22.50^0 of standard deviation for displacement and direction profile respectively.

We also obtain the complete representation of myocardial movement by comparing their displacement profile. As shown in the second column of Fig. 5, it can be stated that all segments have a uniform profile according to their uniform displacement, i.e. about 0.3 pixels. This fact suits with the previous understanding that the normal cardiac should has a uniform displacement of myocardial segments.

VI. Conclusion

This paper has described the extraction of cardiac profile based on the computed optical flow. It consists of displacement and direction profile which will be very useful information for cardiologist to diagnose the abnormality of cardiac. The capability of motion estimation and the profile extraction looks promising based on our preliminary result. The displacement and direction profiles reveal true movements of myocardial segments. The computed cardiac profile also shows a uniform displacement for normal cardiac movement. In future work, the accuracy of motion estimation should be improved and quantified using larger database. Other parameters which represent the myocardial profile should also be determined to provide more integral information for cardiologist.

Acknowledgment

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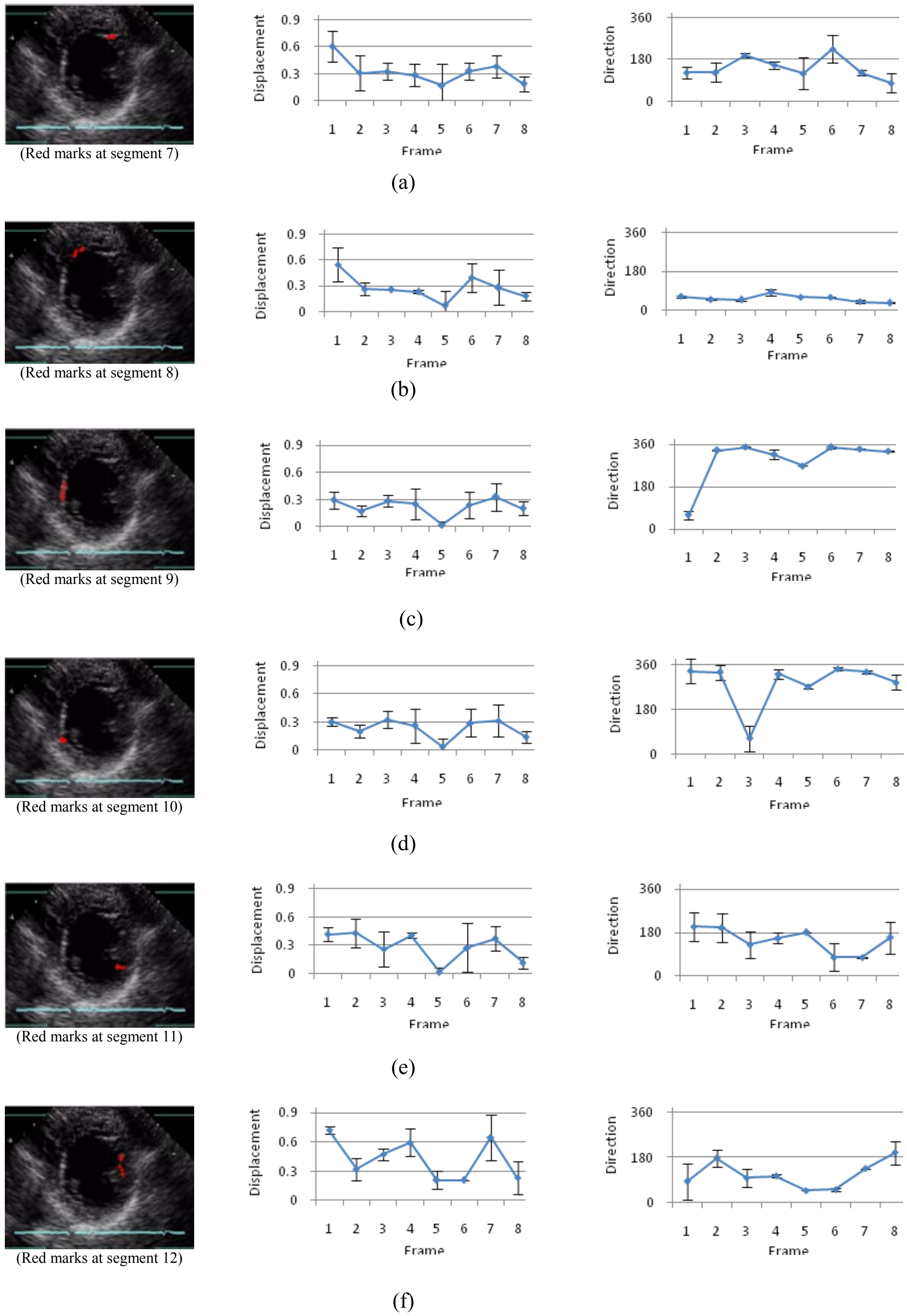

Fig. 5 Profile of myocardial movement: selected points with red marks (1st column) at each segment, its displacement profile (2nd column), and direction profile (3rd column)