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Myocardial Motion Analysis using Modified Radial Direction Distribution based on Magnitude Criteria

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***Abstract*—Accurate information on myocardial motion is important in diagnosing cardiac abnormalities. In this research, the motion vectors are computed using an optical flow technique and further analyzed based on the magnitude and angle. We utilize a relative motion direction with respect to the center of the cavity, which is more useful for diagnosis because a physician can observe whether a segment is moving to the center or not more clearly. Instead of analizing individual vectors, it is more helpful to visualize the overall trend by performing their angular distribution. However, a common angular distribution considers motions with small and large magnitudes to have only an equal contribution and often fails to represent an accurate motion direction of a segment if there is a wide distribution of vector angles in the respective segment. In this paper, we propose a new method of providing an accurate radial direction profile by modifying the contribution of the motion vectors to the radial direction distribution based on a certain magnitude function. This method has been tested on clinical echocardiography sequences and shown to be successful in providing a more accurate radial direction profile compared with the common angular distribution.**

Keywords-echocardiography image; myocardial motion; radial direction profile; magnitude function

I. INTRODUCTION

In 2004, cardiovascular disease caused 17.1 million deaths, which corresponded to 29% of the global deaths for that year as reported by the World Health Organization [1]. 7.2 million of them died because of coronary heart disease, known as “heart attack”, which occurs when there is an interruption of blood supply to the heart muscle. It can be detected early by observing abnormality in the motion of the left ventricular. Realizing the importance of this motion, many researchers have focused on the estimation, quantification and interpretation of cardiac motion [2][3][4][5][6][7].

II. PREVIOUS WORKS

Current research on the cardiac motion of echo images is mainly focused on the improvement of the accuracy of the motion estimation as there have been difficulties in the detection of motion using echocardiography images. The difficulties may be caused by the presence of speckle noise, which is introduced by the limitation of the ultrasound modality and improper image acquisition. On the other hand, quantification of the computed motion will be very useful for physicians to interpret the cardiac motion for making a clinical decision. Few publications report on quantification and interpretation of computed motion on echo images. Ledesma-Carbayo et al. computed the mean displacement vector and the mean strain tensor of each segment from computed myocardial motion [3]. Both features showed significant differences between normal and abnormal cardiac motion. However, the presented features did not provide a complete segmental profile of cardiac motion in a temporal observation. In another proposed method, Duan et al. developed a four-dimensional optical flow frame-work to track the endocardial surface using real-time 3 dimensional ultrasound. Some features, such as flow magnitude, radial displacement, circumferential displacement, thickening, circumferential and longitudinal stretch and twist, were computed to provide dynamic measurement of cardiac motion [6]. The extracted information was mostly used to visualize real-time 3 dimensional cardiac motion rather than to detect cardiac abnormality.

In clinical practice, a cardiologist does not only need to observe the magnitude of myocardial motion, but also the direction of its motion with respect to the center of the cavity to ensure a normal LV ejection fraction. The radial direction distribution is able to provide an accurate trend of the motion direction if the motion vectors on a segment have uniform angle distribution. Otherwise, if there is wide angle distribution, the magnitude significantly influences the distribution of radial direction. In terms of providing accurate orientation distribution, Dalal and Triggs introduced a histogram of oriented gradients (HOG) descriptor for robust human detection [8]. The method successfully implements several stages of computation to perform well-normalized local histograms of gradient images in a dense grid. One of the stages is computing a fine orientation binning to provide an orientation histogram over local spatial regions. In this computation, they interpolated the votes, i.e., functions of gradient magnitude, between the neighboring bin centers in both orientation and position to reduce aliasing. The function of a gradient magnitude, i.e., its magnitude, its square or square root, represents the degree of the presence or absence of an edge at a pixel.

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III. PROPOSED APPROACH

Inspired by the use of well-known HOG descriptors, this paper proposes a new method to provide an accurate radial direction profile of each segment utilizing certain magnitude criteria. In our study, we derive a band-pass linear weighted function to extract the dominant direction from the distribution pattern. This will result in an angle distribution that is much easier for a physician to quickly identify the pattern of segmental motion for diagnostic purposes.

The band-pass linear weighted function proportionally emphasizes the contribution of vectors that have magnitudes inside the range $[Q_1 - k(Q_3 - Q_1), Q_3 + k(Q_3 - Q_1)]$ and gives a unit weighting factor for the contribution of vectors with magnitude outside that range. The terms Q_1 and Q_3 are the first and third quartiles of the data, respectively, and k is a constant. Fig. 1 shows a diagram of this weighted function. The linear weighted factor is applied based on an assumption that a higher magnitude of a vector should give a higher contribution to the distribution. The data outside that range are considered as outliers, so the function gives a weighting factor of 1 for those vectors. Therefore, the proposed function is defined as

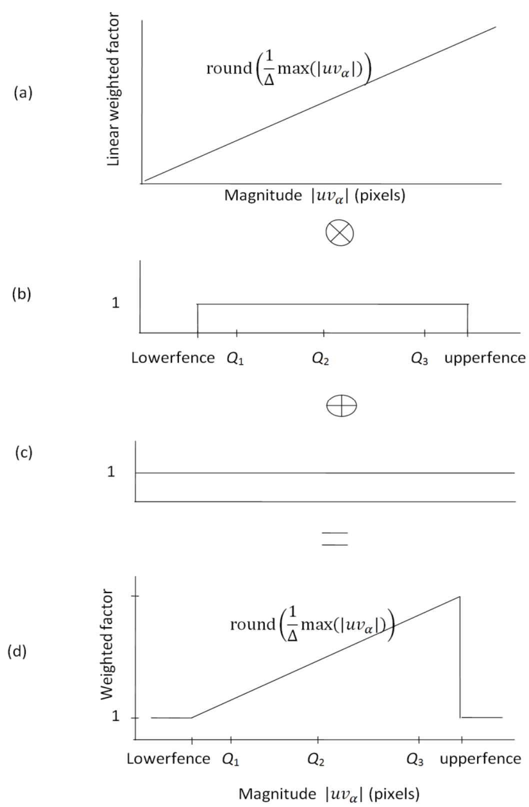

Figure 1. Construction of band-pass linear function: (a) a linear weighted factor, (b) a band-pass filter to select the outliers data, (c) a unit function to maintain the contribution of outliers data on 1, and (d) the complete band-pass linear function.

$$r(\alpha) = \begin{cases} r(\alpha) & |uv_\alpha| \text{ is outside the range} \\ \text{round}\left(\frac{1}{\Delta}\max(uv_\alpha)\right) r(\alpha) & \text{otherwise} \end{cases} \quad (6)$$

where Δ is a scaling value for magnitude.

IV. METHODOLOGY

The proposed method of using an angular radial distribution function to analyze the myocardial motion of a cardiac segment involves several steps. We start with taking two consecutive images of echocardiography sequences. Since it is well-known that echocardiography images contain speckle noise, a quasi Gaussian-Discrete Cosine Transform filter is then applied to improve the image quality [9]. Subsequently, we manually select the cavity center and initial points on endocardium, and then apply B-spline to generate other points along the endocardium. After the creation of myocardium boundary, optical flows for every pixel along the endocardial boundary were computed. A statistical averaging approach is implemented to remove outlier data along the boundary and to generate a smoother boundary optical flow vectors.

To assist with the interpretation of mycardial motion, we utilize a radial direction distribution for each myocardial segment, instead of a single angular distribution of flow vector for all the segments [10]. The radial direction distribution represents a direction pattern of segmental myocardial with respect to the cavity center in such a way that cardiologist can directly know the direction in which a segment moves with respect to the centre of the cavity.

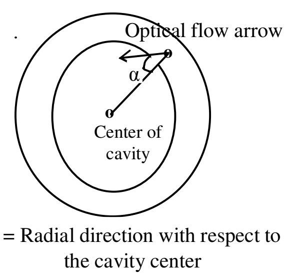

Figure 2. Radial direction of an optical flow

To facilitate the interpretation of myocardial motion, we generated the distribution of radial direction for every segment for each frame. This distribution shows the pattern of direction in such a way that a physician will be able to quickly recognize the direction to which a segment moves. The direction of the segment can be clearly identified for a segment where its radial direction does not vary significantly. Otherwise, in the widely distributed radial direction, this may not be easily done. To overcome this problem, in this paper, we propose a technique that is based on the modification of the contribution of vectors using a band-pass linear weighted function as discussed in Section III.

V. Results and Discussion

The proposed method was implemeted on a set of clinical echocardiography data, which were previously recorded by a physician on a parasternal short axis (PSAX) standard view using a Siemens Acuson Sequoia scanner. We then computed the optical flow vectors of two consecutive images for instance are frames 2 and 3 as shown in Fig. 3 and applied the proposed method to these optical flow vectors.

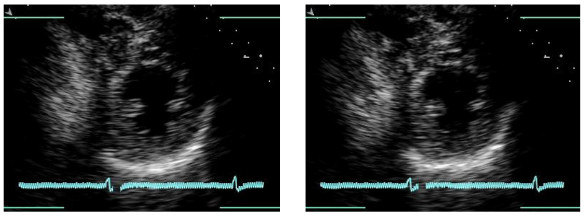

Figure 3. An example of two consecutive frames

In [10], the original distribution is directly generated from the radial direction of every vector flow on the selected segment. For a segment that has vector flows with nearly similar radial direction, this distribution will convey sufficient and correct information about its direction. However, this direct method can produce information on the direction that has some uncertainty when it is used to represent vector flows with a wide distribution of radial direction. Fig. 4(a) is an example of a case of vector flows on the mid-septum (upper left segment) with radial direction spreading from 90^0 to 180^0 as shown in Fig. 4(b). In generating this distribution, every vector gives the same contribution to the distribution of radial direction regardless of its magnitude. A vector of very small magnitude that may not significantly contribute to the segment motion is counted the same as other vectors with a large magnitude that actually drive the segment motion. Similarly, a vector of a very large magnitude that may occur due to an error of optical flow computation is also accounted for. In such a situation, the distribution may not be accurate, and it will be difficult to determine the dominant direction of this segment. In the generation of a modified radial direction profile, we propose a weighting function that gives a contribution factor of 1 for vectors with very low and very high magnitude and a contribution factor that is proportional to the magnitude for vectors inside the range $[Q_1 - k(Q_3 - Q_1), Q_3 + k(Q_3 - Q_1)]$. The result of applying this function is a new distribution pattern as shown in Fig. 4(c). This distribution represents a more accurate cardiac motion segment with the dominant direction at a certain angle. It is evident from Fig. 4(c) that after application of this weighted function, the profile is more representative and easier to use in determining the pattern of motion compared with one without a weighted approach applied.

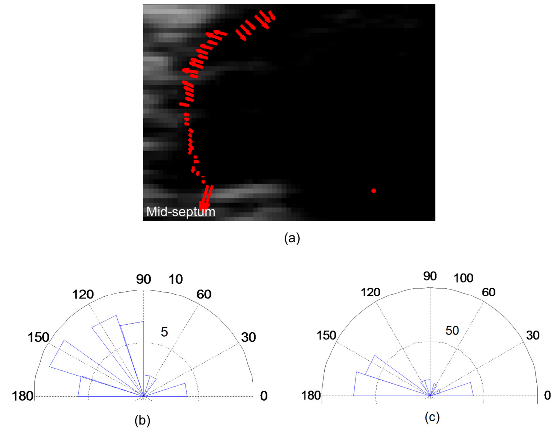

Figure 4. Vector flows along the mid-septum segment boundary, (b) original distribution of radial direction, which has a wide distribution, and (c) modified distribution of radial direction after applying the band-pass linear weighted function, which produces a dominant direction of 180^0.

Table 1 shows the complete results of the distribution of radial direction with and without the application of the band-pass linear weighted function on each segment. It can be seen that in the modified distributions, the dominant direction is more pronounced at a certain angle; hence, they are more helpful in determining the dominant direction of myocardial motion compared with the one without any scaling applied. Although the weighted function generally reconstructs the distribution to be dominant at a certain angle, the function does not force the distribution to have one dominant direction as such in the modified distribution of the mid-anterior and mid-septum on the Table 1. It agrees with the facts confirmed by cardiologist that a certain part of a segment may have a different motion either in terms of its magnitude or direction due to the irregular motion of the myocardium.

VI. Conclusion

The radial direction is easier for physician to analyze the myocardial motion instead of common angular distribution as well as more invariant to segment locations. To achieve more accurate profile, a new method to modify the radial direction distribution is presented in this paper. The proposed method utilized a band-pass linear weighted function, which gives a different contribution to the distribution of radial direction based on the magnitude of the motion vectors. This function has been shown to be capable of producing a more accurate profile compared with the common angular distribution, and it enables a physician to easily interpret the motion pattern of a cardiac segment for diagnostic purposes.

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TABLE I. DISTRIBUTION OF RADIAL DIRECTION WITH AND WITHOUT APPLICATION OF THE BAND-PASS LINEAR WEIGHTED FUNCTION ON EACH SEGMENT.

Flow vectors along boundary segment	Original distribution of radial direction	Modified distribution of radial direction