Adaptive detection research of omni-directional M-mode echocardiography image's boundary

--a method to determine motion track of cardiac structure

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Abstract-This article introduce an adaptive method to detect omni-directional M-mode echocardiography image's boundary based on correlation principles (including time correlation, position correlation and gray-level correlation). The boundary curve can represent the function that intersection position of cardiac boundary and the sampling line (ultrasonic wave-beam) stretched by time, which is a method to get the movement track of a certain structure part. The boundary track includes much correlation information. Based on the correlation information, incremental hierarchy policy which combined with linear template and effective range probe can be used to realize auto detection of motion curve. The method can get motion curve effectively. It is the precondition to get important parameters such as velocity, acceleration, which is used for quantitative analysis of cardiac function.

Key words- omni-directional M-mode echocardiography image, boundary detection, adaptive, correlation

Ⅰ. INTRODUCTION

Omni-directional M-mode echocardiographic images is built by sampling a set of sequential gray-points, which are fixed on the sampling line, from sequential echocardiographic images of 2-D cross section. The technology is easy to realize, furthermore, it could clearly display the quick moving status of cardiovascular structure. Omni-directional M-mode echocardiographic moving curve could accurately and quantificationally detect heart's texture moving amplitude, velocity, acceleration[1] and ventricular thickness, interior diameter of cardiovascular. It has very important contribution to partial and global quantificational evaluate of heart's function.

Our research is based on omnidirectional M-mode echocardiographic images which are more scientific, accurate and creditable than general M-mode echocardiographic images because the position and direction of sampling line corresponding to general M-mode echocardiographic images are limited due to the confined direction of ultrasound wave beams while the position and direction of sampling line corresponding to omnidirectional M-mode echocardiographic images are free. But the quality of the omnidirectional M-mode echocardiographic image is less than general M-mode echocardiographic image, because it comes from 2-D ultrasonic image. In addition, ultrasonic image has some characteristics: 1) dim outline of gray, because of the noise signal and vermicular motion of vascular tissue. 2)partial area effect, because that the range of edge image may contain edge element and tissue element, it is difficult to exactly describe the relation among boundary, corner and tissue area, some abnormal tissue attack adjacency tissue so it is not able to get the boundary. 3) some uncertain reason (like abnormal changes etc.). These reasons badly obstruct getting the exactly moving curve.

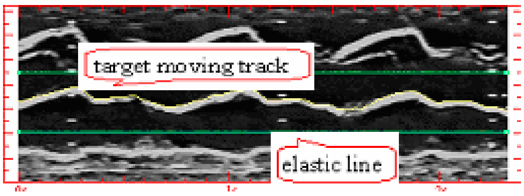

Figure1. Omnidirectional M-mode echocardiographic image with its movement track

An omnidirectional M-mode echocardiographic image probably consists of complicated gray information, which reflects several movement tracks simultaneously. as shown in figure 1. So we called the track which we want to get target moving track. One column pixels stands for one frame gray points fixed on sampling line. The M-mode echocardiographic images is the time extraction of a set of gray points standing for the stretched movement track of a certain boundary of cardiac structure caused by hemodynamics together with cardiac muscle bounce. Consequently, the image contains abundant information of time correlation, position correlation and gray level correlation. The purpose of this paper is to present a method of nearly automated, adaptive and hierarchical for extracting movement track layer by layer according to its inherent characteristics and correlations of time, position and gray level.

Ⅱ. METHODOLOGY

1. Preprocessing

The presence of gray information, which

reflects other movement tracks, badly impedes the extraction on the target movement track. Additionally, due to the inherent characters of echocardiography including low contrast, speckle noise and signal dropouts, we employ elastic lines[2] to manually enclose a rough target area where much interferential gray information is excluded, as shown in figure 2(a). The simple but practical method saves us much trouble when the interferential gray information is difficult to be excluded by automatic computer processing. For this reason, the extraction for movement track is defined as nearly automated. However, the approach of enclosure with elastic lines could be neglected when target area is legible in image.

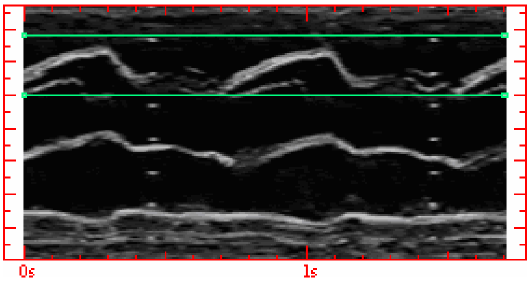

Figure 2（a）. Enclosure with elastic lines

Figure 2（b）. target area after threshold segment

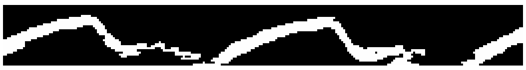

Figure 2（c）. target area after threshold segment and region connection

1.2 threshold segment and region connection

Considering the shadows and inhomogeneous luminosity in the image, we choose the dynamic partial threshold iterative algorithm for gray statistic, and then apply binary segmentation on image with threshold array. The detailed process for a dynamic partial threshold is:

[1] Evaluate the maximal and minimal gray level $\mathbf{Z_{max}}$, $\mathbf{Z_{min}}$ in partial target area (7 column pixels range), then define the initial threshold $\mathbf{T_0}=(\mathbf{Z_{min}}+\mathbf{Z_{max}})/2$;

[2] Segment current partial target area into two parts with $\mathbf{T_k}$, calculate the mean gray value $\mathbf{Z_O}$, $\mathbf{Z_B}$ of two parts, then command $\mathbf{T_{k+1}}=(\mathbf{Z_O}+\mathbf{Z_B})/2$;

$$Z_0 = \frac{\sum_{z(i,j)<T^k} z(i,j)\times N(i,j)}{\sum_{z(i,j)<T^k} N(i,j)}, \quad Z_B = \frac{\sum_{z(i,j)>T^k} z(i,j)\times N(i,j)}{\sum_{z(i,j)>T^k} N(i,j)}$$

[3] If $\mathbf{T_{k+1}}==\mathbf{T_k}$, command $\mathbf{T_{k+1}}$ as the threshold of the current partial image, otherwise, return to **[2]** for further iterative threshold.

After binary segmentation with threshold array, we get Figure 2（b）. Then, region growing of 4-neighborhood algorithm is employed to connect points, mark regions and make statistic on size (counted in pixel) of each region and the total size of regions. Considering the periodicity of M-mode echocardiographic images and potential track dropouts evoked by signal dropouts, we choose 1/5 as size threshold of regions. The region whose size is greater than 1/5 of total size is picked out, then we defined the region which is not lengthways overlap with other picked region as candidate region. The desired movement track is usually restricted along these candidate regions in most omnidirectional M-mode echocardiographic images. The result is shown in figure 2(c).

1.3 probing effective range

Generally speaking, the edge of image exists in diverse directions. Classic edge detection algorithms are partly carried out with both horizontal template and vertical template, utilizing the law of one order or two order differential coefficient of gray points near the edge, and partly carried out with dynamic mode of manual intervention to extract the edge when gray lever distribution near the edge varies complicatedly. Though the respective advantages of these classic algorithms, they are inadequate for the extraction of movement track in omnidirectional M-mode echocardiographic images. Expect for the limitation of each algorithm oneself, what is more important is the inherent characteristics of omnidirectional M-mode echocardiographic image, the movement track consists of sequential intersecting points of cardiac ventricle wall and sampling line. Consequently, the desired movement track can be described as a one-dimension function that varies in vertical direction. Furthermore, due to the finite amplitude of diastole and systole, we restrict the probe range non-linearly.

$$\begin{cases} S_A - \dfrac{d^2+d-1}{d} * v_p \le S \le S_A + \dfrac{d^2+d-1}{d} * v_p, & 1 \le d \le 4 \\ S_A - 5 * v_p \le S \le S_A + 5 * v_p, & else \end{cases} \quad \cdots\cdots(1)$$

Parameter d stands for interval (counted in pixel) of current column and its nearest identified track point, S stands for the effective probe range of current column, S_A is the Y-coordinate value of its nearest identified track point,v_0 =$(v_a*t_0)/h_0$, v_a =10cm/s (v_a is little greater than max velocity of heart cardiac muscle), h_0 stands for actual high of every pixel, t_0 stand for the interval time between two column pixel. The nonlinear coefficient $(d^2+d-1)/d$ changes S according d nonlinearly.

1.4 Linear template

We design the 1-D linear template according to the time correlation, position correlation and gray level correlation of omnidirecti- onal M-mode echocardio- graphic images, as shown in figure 3. The linear template functions in effective probe range, when meets four following conditions, the current position will be identified as track point of current column.

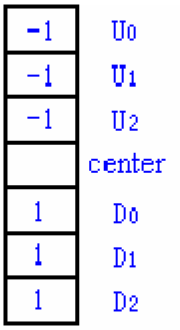

Figure 3

A. Gray levels of U_0、U_1、U_2 are all lower than threshold g_T we have calculated from dynamic partial threshold iterative algorithm, and gray levels of D_0、D_1、D_2 are all higher than threshold g_T.

B. $G=(D_0+D_1+D_2-U_0-U_1-U_2)/3$, the gradient of current position is maximal in the effective probe range.

C. The difference of mean of D_0、D_1、D_2 and its nearest identified track point is less than half of current gradient.

D. There is no candidate point belongs to the same connected region above the current probe position in 4-neighborhood connected binary image.

2 Processing Flow

The extraction is serial and hierarchical from layer to layer. The identification of high layer track points is based on the identified track points of its lower layer. Consequently, exactness of lower layer track points severely affects the final extracting result. For this reason, sufficient strict conditions are employed necessarily to guarantee the extraction exactness of movement track. The detection flow char is shown in figure 4.

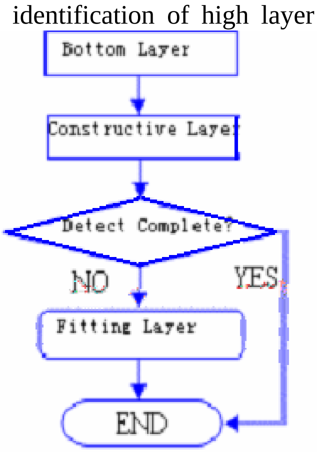

Figure 4. detection flow char

2.1 Bottom layer

Due to the particular position characteristic of wave crests, speckle noise and signal dropouts affect the edge character of wave crests much slightly than other positions in most omnidirectional M-mode echocardiographic images. Obviously, track dropouts rarely occur near wave crests. Consequently, we capture bottom layer track points (are also defined as seed points) near wave crests. Firstly, we detect wave crests from top to down and left to right in the candidate regions of 4-neighboehood connected binary image[3]. As shown in Figure 6, when a target point is detected, and it belongs to the first or second largest connected area, it can be decided as a wave crest.

When the first wave crest is detected, considering the cardiac periodicity, we search for second wave crest in the candidate region apart from previous wave crest between 0.6s and 1s(it is the normal cardiac periodicity), analogize sequentially. Range forecast formula is shown in formula 2.

$$\begin{cases} t_A - 1.1 \le t_B \le t_A - 0.5 & \text{ahead} \\ t_A + 0.5 \le t_C \le t_A + 1.1 & \text{backwards} \end{cases} \quad \cdots\cdots(2)$$

t_A stands for time of wave crest A, t_B and t_C is the time forecasted by wave crest A.

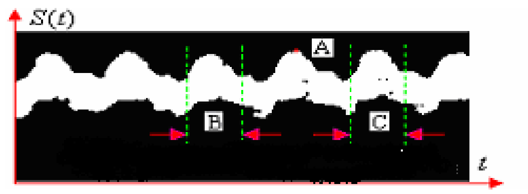

Figure 5. wave crest A forecast the possible range of neighborhood wave crest B, C

Then we probe for seed points with linear template in 25-neighborhood of these wave crests in primitive image. If meets the template condition **A**, **B**, **D**, the current position will be identified as seed points, as shown in figure 6.

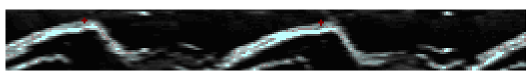

Figure 6. result of bottom layer detection (achieve two seed points)

2.2 Constructive layer

The extraction of bottom layer track points is crucial because these seed points will guide the further extraction. However, we can't describe the desired movement track with so sparse points. Therefore, combining with the bottom layer track points, the linear template extraction in effect probe range proceeds. When meets all template conditions, the current position will be identified as track point. Time correlation and position correlation behave as the restriction on probe range, and gray level correlation behaves as template condition **C, D** in process. The detailed process:

[1] Utilizing identified track points and formula 1, we extract track points from left to right. If one position of current column meets all Linear template conditions A,B,C, D, identify it as track point and move to its next right column for next track point, otherwise, move to the next right column for next track point straightly. The extracting result is shown in figure 7.

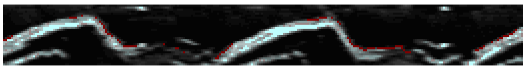

Figure 7. The result of constructive layer 1 extraction

[2] Change to meet Linear template conditions A, B, D, other condition is the same as **[1].** Because **[2]** is on the basis of **[1],** it did not use condition C, other conditions could still give a guarantee to our result. The extraction result is shown in figure 8.

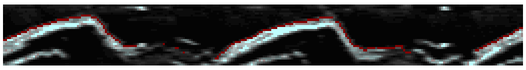

Figure 8. The result of constructive layer 2 extraction

[3] Generally, there are still some columns whose track point can't be identified after above two steps. If candidate point belongs to target regions exists in current column and the point is among the Y-coordinate values of the nearest left and nearest right identified track points, both the Y-coordinate values will be introduced as new probe range for linear template. When it meet Linear template conditions B, C, D, identify it as track point. The extracting result is shown in figure 9.

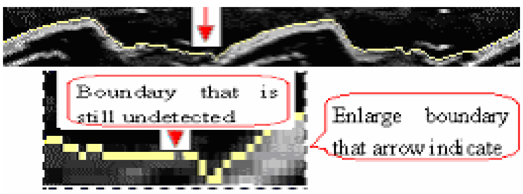

Figure 9. The result of constructive layer 3 extraction

3.3 Fitting layer

We can't make guarantee for extracting an uninterrupted movement track through bottom layer and constructive layer, especially in a severe noise or track dropouts image. However, the unidentified track points are sparse after extraction of above two layers. Consequently, we employ Curve Fitting of Minimal Mean Square Error (**MMSE**) combined with position correlation to integrate a whole track. If track point of current column is unidentified, seek for its six nearest identified track points $\{(x_i, y_i), i = 1,2,\cdots,6\}$, then seek for a quadratic function $f(x) = c_0 + c_1 x + c_2 x^2$ to meet $MSE = \frac{1}{6}\sum_{i=1}^{6}[y_i - f(x_i)]^2$ ……(3)

The task of **MMSE** is to evaluate coefficient c_i. Expressed as matrix, if

$$Y = \begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_6 \end{bmatrix}, M = \begin{bmatrix} 1 & x_1 & x_1^2 \\ 1 & x_2 & x_2^2 \\ \vdots & & \\ 1 & x_6 & x_6^2 \end{bmatrix}, C = \begin{bmatrix} c_0 \\ c_1 \\ c_2 \end{bmatrix} \cdots \quad (4)$$

Error matrix will be expressed as

$$E = Y - MC \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (5)$$

and formula (1) will be expressed as

$$MSE = \frac{1}{6} E^T E \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots \quad (6)$$

Put formula (3) into formula (4), then evaluate the differential coefficient of, and command the differential coefficient as 0, we will extract

$$C = [M^T M]^{-1} [M^T Y] \cdots\cdots\cdots\cdots\cdots\cdots \quad (7)$$

C is the coefficient we desire. According to $f(x) = c_0 + c_1 x + c_2 x^2$, we fix the track point of current column. As shown in figure 10 .

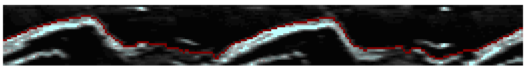

Figure 10. The extraction after fitting layer

Ⅲ.RESULT OF EXPERIMENT

Incremental hierarchical layer processing improve the reliability of target motion curve. When the gray between motion curve and other part in an omnidirectional M-mode echocardiographic image has high contrast, or there is only one motion curve, Preprocessing could be omitted. The example is shown in figure 11(a) and figure 11(b). Otherwise, Preprocessing should used to strict target area, then use incremental hierarchical layer processing to get satisfying result. The example is shown in figure 12.

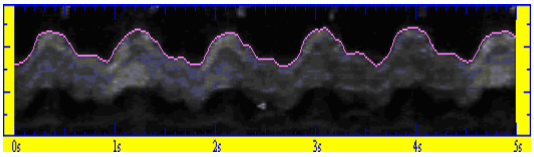

Figure 11(a). Result of and incremental hierarchical layer processing, preprocessing is not used because image has little disturb signal.

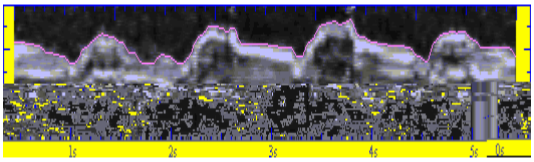

Figure 11(b). Result of and incremental hierarchical layer processing, preprocessing is not used because image has distinct boundary characteristic.

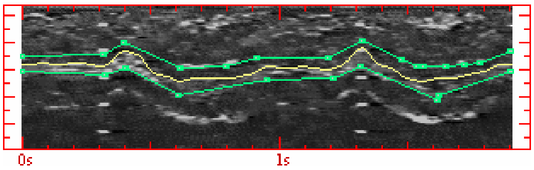

Figure 12. Result of preprocessing and incremental hierarchical layer processing

IV. CONCLUSION

We have implemented a method for extracting the movement track of cardiac structure gray-points. Application has demonstrated the encouraging results even without manual interference. The preprocessing step including enclosure with elastic lines, binary segmentation with threshold array, 4-neighborhood connecting and candidate region selection largely removes the severe noise and much interferential gray information, which can't be removed easily by automatic computer processing. Hierarchical layer processing and strict linear template conditions, which are based on correlations of time, position and gray level, guarantee the exactness of extraction.

We have to admit that the extracting method needs further improvement. The detection of wave crests with straight line needs to be combined much closer with prior knowledge of cardiac periodicity. Furthermore, coefficient of linear template can be ameliorated. By far, our extraction of movement track is based on the detection of genuine edge points and an omnidirectional M-mode echocardiographic image might contain spurious edge points and genuine edge points which are not part of the target border. For this reason, sequent manual correction becomes necessary for cardiologists in some images.

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