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Automatic Detection of Region of Interest and Center Point of Left Ventricle using Watershed Segmentation

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Abstract—In the detection of the boundary of the left ventricle from echocardiographic images, the crucial step is to determine the region of interest (ROI) or the center point (CP) of the left ventricle. In this paper, a new algorithm is proposed for automatic detection of the ROI and CP of the left ventricle from echocardiographic images. The method makes use of morphological operations and watershed segmentation. No prior assumption of the approximate location is required and no human intervention is necessary for the proposed approach hence making it most suitable for automatic operation.

I. INTRODUCTION

Automatic boundary detection of left ventricular (LV) from echocardiographic images is an essential task for reliable and objective assessment of the heart function. The first step of many existing methods is the localization of LV center point (LVCP) or determination of an initial contour. For example, the active contour model method [1] requires a good initialization at the beginning of deformation, since the snake is very sensitive to the initial position of the contour. In most instances, the LV center or initial boundary is outlined manually by the user, which makes the algorithm dependent on human intervention to some extent.

In [2], an automatic fuzzy-based method for estimating the location of the LVCP in a single echocardiographic image was proposed. However, its assumption that the LVCP is located approximately in the central part of the image is not valid in all situations. In this paper, a novel approach to automatically locate the LVCP and the approximate LV region is proposed that does away with the limitations mentioned above.

II. LV CENTER DETECTION

A. Preprocessing

It can be observed that in a four-chamber-view gray-scale echocardiographic image (Fig. 1), the interior of the four chambers of the heart are darker than the myocardial walls. This characteristic feature is utilized in the proposed automatic LVCP detection.

Fig. 1. The original echocardiographic image.

To reduce the influence of speckle noise, the original image is smoothed by the adaptive neighborhood smoothing method [3]. As the interior region of the ventricle has intensities consistently below a threshold gray level τ , a large smoothing kernel ($k_l \times k_l$) is used for pixels less than the threshold τ and a small smoothing kernel ($k_s \times k_s$) is used for pixels above τ . The value of τ is obtained by Otsu's method [4]. k_l is set to be directly proportional to the length of the image, and k_s is half the size of k_l . The smoothing step is repeated twice to ensure that the low-intensity regions are smoothed more thoroughly than the high-intensity regions.

B. Binary Image Processing

After the speckle noise is removed by smoothing, the resulting image is then converted to a binary image using the threshold τ as a division criterion.

In the resulting binary image, there may be some extraneous objects and the heart chambers may be connected with one another. To remove the extraneous objects generated by speckle noise or artifacts not previously eliminated by

Fig. 2. (a) The binary image before morphological erosion and (b) after morphological erosion.

Fig. 3. (a) The difference of Fig. 2(a) and Fig. 2(b); (b) the eroded image with the lost object recovered.

smoothing, the holes in the binary image are filled by the following morphological operation. The binary image (Fig. 2(a)) is subjected to a morphological *erosion* with structuring element of size $k_s \times 3$ to separate the overlapping chambers.

The *erosion* of a binary image A by structuring element B , denoted by $A \ominus B$, is expressed as the set of points x where B_x can be positioned such that B is completely contained in A [5]:

$$A \ominus B = \{x | B_x \subset A\}. \quad (1)$$

As a result of the operation, most of the artifacts are removed and the cardiac chambers in the image are reduced in size.

C. Four-chamber Detection

After morphological *erosion*, the four cardiac chambers are disconnected to one another. However, these objects may be over-eroded. For example, the right ventricle on the top-left of Fig. 2(a) disappears after the erosion (Fig. 2(b)). To restore the chamber, further image processing is carried out.

Firstly, the eroded image is subtracted from the pre-erosion image. If an object in the difference image (Fig. 3(a)) is connected with any other object in the eroded image, it is discarded. After this operation, the modified difference image is subtracted from the pre-erosion image, generating a modified eroded image (Fig. 3(b)). At the completion of this step, four regions corresponding to the four cardiac chambers are visible and separated.

D. Watershed Segmentation

The Euclidean distance transform of the resulting image is computed (Fig. 4(a)). The intensity of each pixel in the image is assigned by the distance between the pixel and the nearest nonzero pixel of the binary image. To accomplish binary image segmentation, watershed immersion algorithm [6] is applied to the Euclidean distance map.

For an image f defined on a digital grid: $\mathcal{X} \subset \mathbb{Z}$, the catchment basin CB_i of a regional minimum $\mathcal{M}_i$ ($i = 1, \dots, K$) is

defined by:

$$CB_i = \{x \in \mathcal{X} \mid \forall j \neq i, 1 \leq j \leq K : \alpha_i + L_i(x) < \alpha_j + L_j(x)\}. \quad (2)$$

where α_i is the level of f on $\mathcal{M}_i$, and $L_i(x)$ is the corresponding topographical distance transform [7]. $WS(f)$, the watershed line of the image f , is the set of points not belonging to any catchment basin $CB(\mathcal{M}_i)$:

$$WS(f) = \mathcal{X} \setminus \bigcup_i CB(\mathcal{M}_i). \quad (3)$$

At the location of overlap in the binary image, there is a ridge in the corresponding map where the two catchment basins of each overlapping objects meet. Each of the two catchment basins is labeled uniquely and the lines separating them is labeled as a chamber watershed (Fig. 4(b)).

The binary image is then masked by multiplication with the label image. Every object in the masked binary image (Fig. 4(c)) is labeled with different integer value for distinct identification. Objects connected to the image border (ultrasound fan area) are removed from the image (Fig. 4(d)). Only the four objects corresponding to the heart chambers are retained. The left ventricle is selected based on anatomical knowledge. In this particular case, LV is the object on the top-right of the image. In the watershed label map, the catchment basin to which this object belongs is considered as the region corresponding to the LV.

E. Post-processing

The intensity of the pixels in LV region is set to 1 and the rest to 0. The resulting mask image (Fig. 5(a)) defines the region of interest (ROI) for subsequent processing. The ROI is then morphologically dilated by k_s pixels to include the necessary edge information near the LV boundary. The center of ROI is then taken as LVCP.

III. INITIALIZATION FOR LV BOUNDARY DETECTION

The LV endocardial (interior) boundary can be detected based on the identified ROI and LVCP. The ROI's border

Fig. 4. (a) The Euclidean distance map; (b) watershed segmentation; (c) the masked binary image; (d) after removing fan area.

is adopted as the initial LV boundary (Fig. 5(b)). Boundary detection technique can then be applied within the ROI to reduce unnecessary computing of image data out of ROI.

To segment the LV in a sequence of echocardiographic images from a cardiac cycle, it is not necessary to identify the LVCP for every frame as its position does not significantly change from frame to frame. To enhance the intensity of the boundaries for LVCP tracking, a composite image (Fig. 6(a)) is constructed as follows. For each pixel, the intensities of the corresponding pixels of all the frames are compared and the maximum value is used for the composite image.

The same procedure as described for a single image is then applied to the composite image. In the watershed label map of the composite image, the catchment basin corresponding to the left ventricle is dilated to include the necessary edge information near the LV endocardial boundary and this also serves to define the ROI for subsequent processing (Fig. 6(b)). Thus the ROI and LVCP for the composite image are detected.

IV. CONCLUSION

A novel method using morphological operations and watershed segmentation is proposed to automatically detect the center of the left ventricle from echocardiographic images. The proposed method does not require human intervention. The location of the LVCP is tracked automatically and the parameters are adjusted adaptively. The proposed method of

Fig. 5. (a) The LV mask image; (b) LVCP (indicated by a 'plus' sign) and initial LV boundary (in white line).

Fig. 6. (a) The composite image from a sequence of echocardiographic images. (b) The ROI (enclosed by the white line) and LVCP (indicated by a 'plus' sign).

localization of ROI reduces the interference from artifacts and also provides an initial contour for LV boundary detection.

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