International Journal of Medical, Medicine and Health Sciences
ISSN: 2517-9969
Vol:9, No:3, 2015

Automatic LV Segmentation with K-means Clustering and Graph Searching on Cardiac MRI

Hae-Yeoun Lee

***Abstract*—**Quantification of cardiac function is performed by calculating blood volume and ejection fraction in routine clinical practice. However, these works have been performed by manual contouring, which requires computational costs and varies on the observer. In this paper, an automatic left ventricle segmentation algorithm on cardiac magnetic resonance images (MRI) is presented. Using knowledge on cardiac MRI, a K-mean clustering technique is applied to segment blood region on a coil-sensitivity corrected image. Then, a graph searching technique is used to correct segmentation errors from coil distortion and noises. Finally, blood volume and ejection fraction are calculated. Using cardiac MRI from 15 subjects, the presented algorithm is tested and compared with manual contouring by experts to show outstanding performance.

***Keywords*—**Cardiac MRI, Graph searching, Left ventricle segmentation, K-means clustering.

I. Introduction

CARDIAC disease is the leading cause of death in the world. To diagnose cardiac diseases, analyzing and monitoring cardiac function are important in routine clinical practice by calculating blood volume and ejection fraction in diastolic and systolic phases. Magnetic resonance imaging (MRI), computed tomography, ultrasound, and X-ray are used to quantify cardiac function. Since MRI does not expose patients to ionizing radiation, it is suitable for routine cardiac checkups.

To segment blood region in diastolic and systolic phases, manual contouring has been performed in clinical practice, which has been considered the gold-standard for blood volume and ejection fraction quantification. However, it is a labor-intensive and time consuming process and dependent on inter- and intra-observer variability because of the complex cardiac structure such as papillary and trabeculae muscles.

To overcome these difficulties, a computer algorithm segmenting blood region of left ventricle (LV) minimizing human interaction is required. In this paper, an automatic LV segmentation algorithm is presented which uses K-means clustering and graph searching on cardiac MRI. Since the shape of LV is circular, a circular map is generated by polar mapping from a coil-sensitivity corrected image. K-means clustering is applied to segment blood region on the circular map. Segmentation errors are corrected by a graph searching scheme. Using cardiac MRI from 15 subjects, the presented algorithm is tested and compared with manual contouring by experts.

This paper is composed of as follows. Section II shortly reviews LV segmentation researches. An automatic LV segmentation algorithm is presented in Section III. Experimental results are shown in Section IV and Section V concludes.

Hae-Yeoun Lee is with the Kumoh National Institute of Technology, Gumi, Gyeongbuk, Republic of Korea (phone: 82-54-478-7548; fax: 82-54-478-7539; e-mail: haeyeoun.lee@kumoh.ac.kr).

II. Related Works

Many cardiac LV segmentation methods have been studied to calculate blood volume and ejection. These methods are categorized as follows: traditional segmentation algorithm, graph-based algorithm, active contour model algorithm and level-set algorithm [1].

Traditional segmentation methods are useful to recognize complex LV structures such as papillary and trabeculae muscle. However, segmentation parameters should be determined by the experience of the observer and hence designing an automatic LV segmentation algorithm is difficult, especially, in basal and apical slices [2].

Graph-based segmentation methods generate a cost-graph by considering the intensity of the pixel and the intensity difference among adjacent pixels. Then, a minimal cost path is found to segment LV. However, complex LV structures such as papillary and trabeculae muscles cannot be easily segmented. Moreover, it disturbs finding the minimal cost path [3].

Active contour model (ACM) methods segment a region by minimizing the internal and external energy of the modeled object. These methods set the model to the boundary of the LV and minimize energy by repeating calculation. The low contrast of cardiac MRI usually causes problems in accuracy and the performance is unstable depending on the initialization [4].

Level-set algorithms are applied to segment objects in low-contrast and noisy images. However, level-set algorithms should be performed iteratively to segment objects. Hence, it requires high computational costs and initialization near to objects for the segmentation accuracy [5].

Each method has trade-off among accuracy, time complexity, and inter-or intra-observer variation. Also, they have many difficulties to handle complex cardiac structures.

III. Automatic LV Segmentation

This section presents a novel automatic LV segmentation algorithm using K-means clustering and graph-searching on cardiac MRI. The presented algorithm is composed of 5 steps: (1) a MRI image is pre-processed and initial LV information is estimated such as seed points, the statistical values of blood region, (2) a circular map is generated by polar mapping, (3) LV is segmented by K-means clustering, (4) segmentation errors are corrected by graph searching and (5) LV is finally segmented by inverse polar mapping and blood volume is calculated. These 5 steps are explained in the following section.

A. Preprocessing and LV Information Estimation

Since MRI images have noisy factors which are sensitive to design an automatic algorithm, we apply medial filter to reduce noisy factors. Then, seed points and initial LV information such as center of gravity (CoG) and intensity statistics are calculated. Also, coil-sensitivity is corrected as shown in Fig. 1.

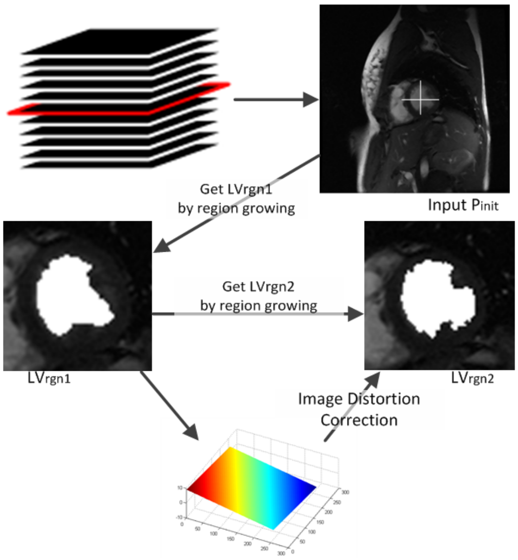

Fig. 1 Estimating LV information with coil-sensitivity correction

1) Seed Point Selection and Propagation

A seed point selection and propagation scheme in [1] and [6] is applied. For the middle slice, a seed point is selected by applying circular Hough transform to the intensity difference image between diastolic and systolic phases. Seed points in other slices are propagated from this seed point as:

$$E(p) = \sqrt{\left(\frac{2\delta_{prev}}{w-1}|P_{CoG} - P|\right)^2 + \left(I_{next}(p) - \mu_{prev}\right)^2} \quad (1)$$

where *E(p)* is the energy of point *P* from CoGpoint P_{CoG} in the previous slice. μ_{prev} and δ_{prev} are the mean and standard deviation of the segmented LV in previous image. $I_{next}(p)$ is the intensity of the point *P*. A window size *w* is set at 11×11. The point having minimum energy is the seed point in that slice.

2) Image Distortion Compensation

Since the location of coils measuring the energy from the object distorts scanned images, it should be considered in designing a computer algorithm. To compensate these coil distortions, we detect an initial LV by region growing with tight constraint and correct coil-sensitivity by estimating a 3D plane and doing planarization in similarly to [1].

B. Circular Map Generation by Polar Mapping

LV is circular. As shown in Fig. 2, to achieve computational efficiency, a MRI image is converted into polar coordinate by polar mapping as follows:

$$P(r,\theta) = \left(\sqrt{x^2+y^2}, acos\frac{x}{\sqrt{x^2+y^2}}\right) \quad (2)$$

where the center of mapping is the CoG of initial LV and the radius is 3 times of the initial LV size. We call the polar coordinated image as a circular map in which a circular searching problem can be solved by linear searching.

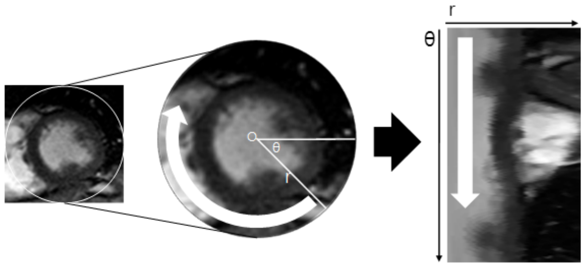

Fig. 2 Generating circular map by polar mapping

C. LV Segmentation with K-means Clustering

To segment LV, K-means clustering is applied on the circular map as shown in Fig. 3. Given an initial set of K means m_1, ..., m_k, which is specified randomly or by some heuristic, K-means clustering proceeds by alternating between assigning and updating steps. In the assigning step, each pixel is assigned to cluster with the nearest mean. In the updating step, a new mean is calculated to be the centroid of the pixels in the cluster [7].

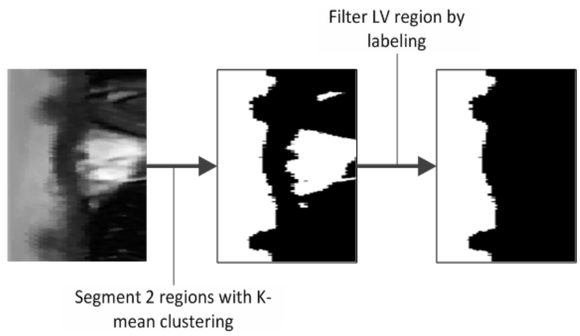

Fig. 3 Segmenting LV with K-mean clustering

In cardiac MRI, the pixel intensity of LV is brighter than that of other regions because LV includes blood (hydrogen). To segment LV from others, we set *K* as 2.

Fig. 4 depicts segmented regions. In segmented regions, the LV is the region including pixels whose radius is 0 on the circular map. Therefore, other regions except the LV are filtered by region labeling. However, because of complex LV structures or in basal slices, some segmented LV includes segmentation errors (see Fig. 4 (c)).

D. Error Correction by Graph Searching

The segmented LV can include errors (other tissues). Especially, in basal slices, segmentation errors occur at all times. To remove these errors, we devise a correction algorithm using graph searching as depicted in Fig. 5.

On the circular map, since the boundary of LV (called as endocardial contour) is linear, a minimal cost path from 0 to 360 degree angle is searched on a graph.

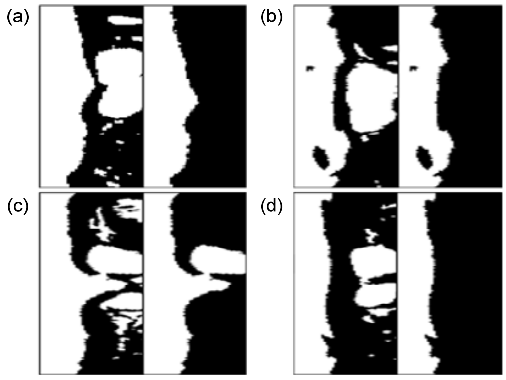

Fig. 4 K-means clustering: correct cases (a, b, and d) and an error case (c) (left) before and (right) after filtering

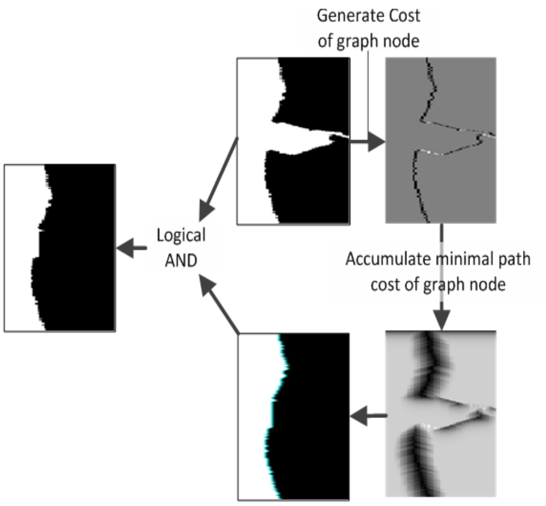

Fig. 5 Correcting segmentation errors by graph searching

The graph is generated by matching a node to the pixel of the circular map. The cost in a node is allocated by calculating intensity difference IMG_{diff} from the segmented LV in a horizontal direction as follows:

$$IMG_{diff}(x,y) = IMG(x,y) - IMG(x-1,y) \tag{3}$$

To find a minimal cost path, the accumulated cost P_{map} of each node is calculated as follows:

$$P_{map(x,y+1)} = \min\begin{pmatrix} P_{map(x-1,y)}, \\ P_{map(x,y)}, \\ P_{map(x+1,y)} \end{pmatrix} + IMG_{diff(x,y+1)} \tag{4}$$

The accumulated cost P_{map} is the summation of the cost of the node itself and the accumulated minimum cost of nodes in previous rows (or angles). From the minimum cost node in the last row (360 degree), the minimum cost path is traced to the first row (0 degree) and that is the boundary of LV. Fig. 6 depicts the corrected segmentation results.

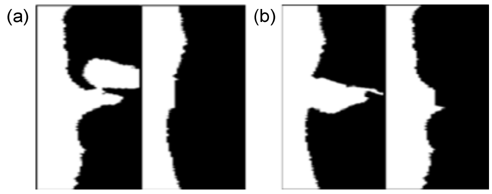

Fig. 6 Error correction by graph searching: (left) before correction and (right) after correction

E. Volume Calculation by Inverse Polar Mapping

Since segmentation is performed on polar coordinate, the LV is mapped to rectangular coordinate by inverse polar mapping $(x,y) = (r\sin\theta, r\cos\theta)$ as shown in Fig. 7. Then, the blood volume of each slice is calculated using slice thickness at scanning. Total blood volume and ejection fraction is acquired by considering all slices in diastolic and systolic phases.

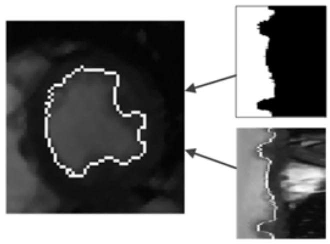

Fig. 7 Calculating blood volume after inverse polar mapping

IV. EXPERIMENTAL RESULT

Using MRI images of 15 subjects taken by a GE SIGNA 1.5T scanner, blood volumes in diastolic and systolic phases and ejection fraction are measured by the presented algorithm and compared with those of manual contouring. User intervention rate is also checked to show the performance of the presented algorithm. Fig. 8 depicts the boundary of the segmented LV with the presented algorithm.

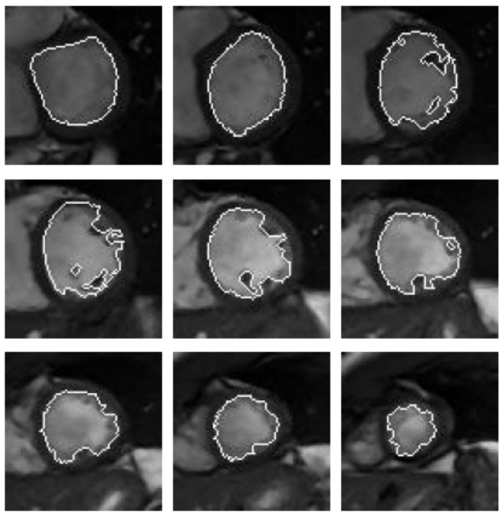

Fig. 8 LV segmentation results

A. Blood Volume and Ejection Fraction

Manual contouring is considered as the gold-standard in clinical practice. We acquired manual contouring results by experts. Blood volumes in diastole and systole were 145.0 mL ± 44.9 and 56.0 mL ± 26.2, respectively. Ejection fraction was 62.7%±9.4.

Table I summarized blood volume and ejection fraction. In the presented algorithm, the blood volume of LV was 146.7 mL ± 41.7 in diastole and 56.7 mL ± 27.6 in systole. Ejection fraction was 63.0% ± 10.2 on average. Overall, results were similar to manual contouring.

TABLE I
COMPARISON OF THE PROPOSED ALGORITHM WITH MANUAL CONTOURING

	Proposed algorithm.
Diastole	146.7 mL ± 41.7
(error)	(4.6 mL ± 3.9)
Systole	56.7 mL ± 27.6
(error)	(2.1 mL ± 2.4)
Ejection fraction	63.0%±10.2
(error)	(1.8%±1.7)

B. User Intervention Rate

User intervention rate was measured to check the possibility of automation. For 135 images in diastolic phases of 15 subjects, the number of images and cases requiring user intervention to segment LV correctly was counted.

Table II summarized the calculated user intervention rate of the presented algorithm. Overall, the presented algorithm minimized the user intervention rate with the accuracy of manual contouring.

TABLE II
USER INTERVENTION RATE

	Proposed algorithm.
Basal	1/135, 0.74% (1/15, 6.67%)
Others	0/135, 0.0% (0/15, 0.0%)

V. CONCLUSION

Manual contouring for quantifying cardiac function is a labor-intensive and time consuming process. Many researches to develop a computerized algorithm have various difficulties because of complex cardiac structures and noisy factors.

In this paper, a LV segmentation algorithm using K-means clustering and graph searching was presented, which achieved high accuracy and small user intervention rate. Future works is improving accuracy to be exactly matched to manual contouring.

ACKNOWLEDGMENT

This research was supported by the 2014 Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education, Science and Technology (2010-0015522)

REFERENCES

[1] H.-Y. Lee, N. Codella, M. Cham. J. Weinsaft, and Y. Wang, "Automatic Left Ventricle Segmentation using Iterative Thresholding and Active Contour Model with Adaptation on Short-Axis Cardiac MRI," *IEEE Trans. on Biomedical Engineering*, vol. 75(4), pp. 905-913, 2010.

[2] J.S. Suri, "Computer vision pattern recognition and image processing in left ventricle segmentation: the last 50 years," *Pattern Analysis and Applications*, vol. 3, pp. 209-242, 2000.

[3] A. Pednekar, U. Kurkure, R. Muthupillari, S. Flamm, and I.A. Kakadiaris, "Automated Left Ventricle Segmentation in Cardiac MRI," *IEEE Trans. on Biomedical Engineering*, vol. 53 (7), pp. 1425-1428, 2006.

[4] M.-P. Jolly, "Automatic Segmentation of the Left Ventricle in Cardiac MR and CT Images," *International Journal of Computer Vision*, vol. 70 (2), pp. 151-163, 2006.

[5] N. Paragios, "A level set approach for shape-driven segmentation and tracking of the left ventricle," *IEEE Trans. on Medical Imaging*, vol. 22 (6), pp. 773-776, 2003.

[6] N. Codella, J. Weinsaft, M. Cham, M Janik, M. Prince, and Y. Wang, "Automatic Soft Segmentation of the Left Ventricle using Myocardial Effusing Threshold Reduction and Intravoxel Computation," *Radiology*, vol. 248 (3), pp. 1004-1012, 2008.

[7] T. Kanungo, D. M. Mount, N. S. Netanyahu, C. D. Piatko, R. Silverman, A. Y. Wu, "An efficient k-means clustering algorithm: Analysis and implementation," *IEEE Trans. Pattern Analysis and Machine Intelligence*, vol. 24, pp. 881–892, 2002.