33rd Annual International Conference of the IEEE EMBS
Boston, Massachusetts USA, August 30 - September 3, 2011

Automatic Quantification and 3D Visualisation of Edema in Cardiac MRI

Kushsairy Kadir*, Hao Gao, Alex Payne, John Soraghan, *Senior Member, IEEE*, and Colin Berry

***Abstract*— Viability assessment of heart muscle after a myocardial infarction is an important step for diagnosis and therapy planning. It is important to quantify the area of edema because it can differentiate between viable and death myocardial tissues. In this paper an automatic method to quantify cardiac edema is presented. The method is based on a combination of morphological operations and statistical thresholding. Using real MRI data it is demonstrated that the proposed method can delineate edema region comparable to manual segmentation with a linear correlation coefficient r=0.76 and the mean difference is around 9.95%. The quantification result is also used to generate 3D visualisation model showing normal myocardial wall and edema region, which will enhance clinician diagnosis capability with real pattern of edema distribution and quantitative description.**

I. Introduction

Myocardial infarction (MI) is a major cause of death in the world. The disease is the result of the complete occlusion of one or more of the coronary arteries, which supply oxygen-rich blood to the heart muscle (myocardium). Therefore clinicians are keen to identify region at risk post MI period from a patient for viability assessments, such as edema. Edema is fluid retention in the myocardium tissue due to damage tissue causing swelling in the affected area of MI. The edema appears as a relatively bright area compared to the normal myocardial tissue as shown is Fig 1 when acquired using T2-weighted CMR imaging sequence. The importance of quantifying edema after an MI is that it can provide a means of assisting the differentiation between acute and chronic MI [1].

Quantification of edema size is normally performed manually where an expert clinician will delineate the left ventricle (LV) wall area and then segment the edema area from the normal wall area. This process is both time consuming and suffers from inter- and intra- observable variations. These motivate the need of developing automatic edema segmentation and quantification methods.

Major challenges in automatic quantification of edema are the weak edge information on epicardium boundary and the present of signal void (shown in Fig.1) due to myocardial haemorrhages. Signal voids are usually included into the edema area by clinicians, but the difficulty is the area has different tissue characteristic compared to the edema. Furthermore, the precise location of the edema as shown in Fig.1 cannot be predicted which complicates the segmentation process.

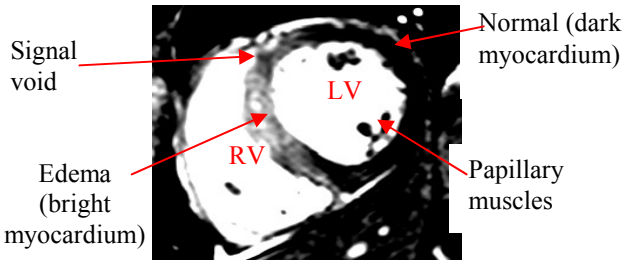


Figure 1: Edema CMR image

Several semi-automatic methods have been developed by using simple intensity thresholding based on the standard deviation (SD) method for edema segmentation. The most commonly used method is 2SD above the mean of normal myocardial intensity [2], [3]. Stalidis et al. [4] applied a contour deformable model to segment myocardial boundary from a T2 weighted CMR image. Once the LV has been segmented the technique requires the user to select several points from each class for the calculation of the mean and the standard deviation to segment the edema region. Regan et al [5] proposed using level set algorithm to segment the edema area, the weakness of this method is that it requires expert to first define the edema boundary before the level set generates single continuous region. Elagouni et al [6] applied fast region competition formulation for accurate edema segmentation. However the work is applied to late-enhancement CMR image. Even though the infarct region in late-enhancement CMR images shares similar intensity characterization as edema region in T2-weighted CMR edema imaging, the problems will be different from those segmentations with late-enhancement CMR images.

In this paper we present an automatic edema quantification method and 3D reconstruction and visualisation of the edema region and normal LV wall

Manuscript received March 31, 2011.*Asterisk indicates corresponding author.*

Kushsairy Kadir is with Centre for excellence in Signal and Image Processing, Dept of Electronic and Electrical, University of Strathcylde, Glasgow G1 1XW, UK and Department of Electrical Engineering, UniKL BMI, Selangor, 53100, Malaysia. (email: kushsairy@eee.strath.ac.uk)

Hao Gao is with Centre for excellence in Signal and Image Processing, Dept of Electronic and Electrical, University of Strathcylde, Glasgow G1 1XW, UK

Alex Payne is with Faculty of Medicine, BHF Cardiovascular Research Centre, University of Glasgow, Glasgow G12 8QQ, UK

John Soraghan is with Centre for excellence in Signal and Image Processing, Dept of Electronic and Electrical, University of Strathcylde, Glasgow G1 1XW, UK

Colin Berry is with Faculty of Medicine, BHF Cardiovascular Research Centre, University of Glasgow, Glasgow G12 8QQ, UK

region. The remainder of the paper is organised as follows. In section II the proposed method is described in detail. The experimental results are discussed in section III. Conclusions are provided in section IV.

II. AUTOMATIC EDEMA QUANTIFICATION

The CMR images are short axis (SA) images consisting of typically 7 slices from the basal to the apical level as shown in Fig 2(a). The automatic 3D edema quantification and visualisation system involves

(i) LV Wall Segmentation, where the stack of CMR images is processed to delineate the LV wall region from the rest of the images as shown in Fig 2(b),

(ii) Edema Segmentation and Quantification in which the result from the LV wall region is used for the segmentation and quantification of edema as shown in Fig 2(c) and finally

(iii) 3D reconstruction and visualisation, where the output of the previous two processes are used to reconstruct the SA axis images into 3D which shows edema region and normal LV wall region as shown in Fig 2(d).

The system will be described in the following sections.

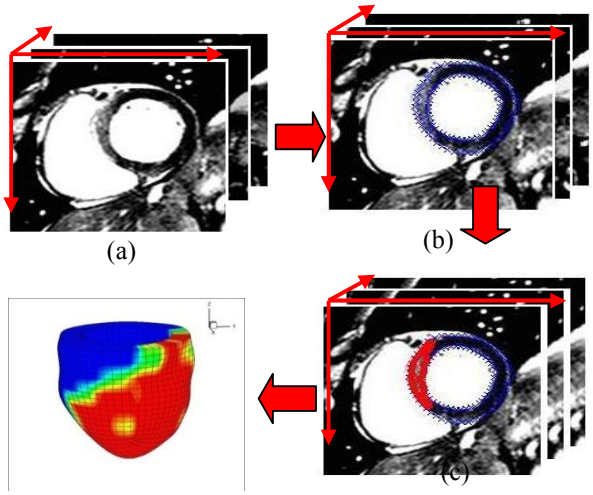


Figure 2: Overview of the process chain, (a) Stack of MRI image from basal to apical, (b) Slice by slice LV wall segmentation, (c) Edema segmentation, (d) 3D visualisation (blue; normal, red; edema)

A. LV wall segmentation

The first step for 3D edema quantification and visualization is to separate the LV wall from the rest of the CMR image. The method takes multi-slice T2 weighted CMR images (an MRI data stack) from the basal to the apex of the heart. It comprises 3 main stages, firstly the image is pre-processed to remove heterogeneity within the blood pool region and also to smooth the LV wall region while preserving the strong boundary using the combination of geodesic morphological operator [7] and traditional anisotropic diffusion method. Then a fuzzy method between inter-slice and intra-slice is used for guiding the centre point detection in each slice for automatic initialisation [8]. Finally the LV wall is segmented variational level set method with shape constraint [9].

B. Edema segmentation

Results of segmentation and edema quantification are shown in figure 3. In this study we adopt a method that was originally proposed in [10]. Fig 3(a) shows the result from LV segmentation and Fig. 3(b) shows the mask of the LV when all other image information has been removed. The presence of small bright areas in the myocardial wall increases the difficulty of accurately classifying edema tissue. To reduce the false positive level, morphological filtering is employed that uses an opening operation with a disk shape structuring element to remove small spurious bright regions. All bright regions having an area of less than 3x3 pixels are removed from the myocardial wall.

The mean and SD of the normal tissue intensities are first estimated by the maximum value of the lower part of the intensity histogram [11] as illustrated in figure 3(c). The threshold value is then calculated as 2SD above the mean. Pixels darker than the threshold are then removed from further analysis as in figure 3(d). The remaining area is then labelled and its size is calculated as in figure 3(e). Areas below a certain empirically threshold are removed. The final bright areas are classified as edema regions. From figure 3(f) two edema region are detected this is due to the failure to include the signal void area as part of the edema region. Iterative dilation is performed as in figure 3(g) to connect the two regions together and finally the final edema contour is shown in figure 3(h).

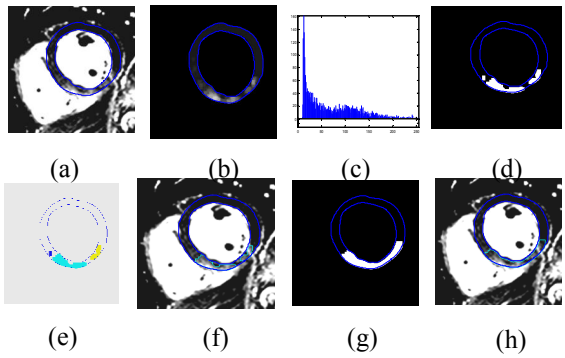


Figure 3: (a) Left ventricle (LV) contour, (b) Pre-processed image, (c) Intensity histogram (d) 2 SD threshold, (e) Region labelling, (f) Segmented region before signal void inclusion, (g) Signal void inclusion, (h) Final Edema contour

C. 3D reconstruction and visualisation

One Edema image slice with a 4-chamber view was segmented to provide the boundary perpendicular to SA images, as shown in Figure 4(a). The endocardial boundary in Figure 4(a) was manually traced. Two points in the base region for mitral valve and one point in the apex were defined, indicated by p1 and p2 in Fig 4(a). The ventricle axis can now be defined as the line between the middle point of p1 and p2 to p3. The positions of SA images along the 4-

chamber view long can be decided from the corresponding DICOM header information, and assembled together as shown in Figure 4(a). The reconstructed 3D geometry of the LV is shown in Figure 4(b) using a hex mesh.

The result of conventional Gaussian smoothing on Fig 4(b) tends to oversmooth the surface as shown in Figure 4(c)

As an alternative the surface was smoothed using a two-step Gaussian algorithm [12] in order to minimize shrinkage. Assuming that p represents the point on surface s and the set of its neighbours are defined as W. The smoothing process consists of iterations of the two stage Gaussian procedure as follows:

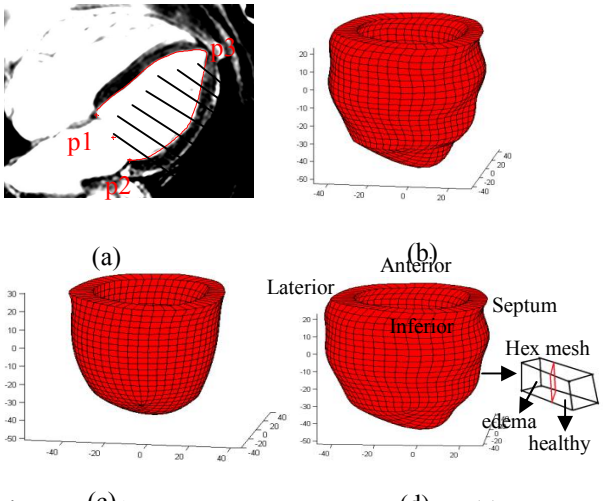


Figure 4: 3D LV geometry generation. (a): Long axis segmentation; (b): original LV geometry reconstruction; (c): LV geometry with one-step Gaussian smoothing(λ =0.34 for all iterations, iteration number=50); (d) LV geometry with two-step Gaussian smoothing(iteration number=50).

1. For all odd-numbered iterations

$$p \to (1-\lambda_1)p + \lambda_1 \sum_{q_i}^{W(i=1...n)} \omega_i q_i$$

2. For all even-numbered iterations

$$p \to (1-\lambda_2)p + \lambda_2 \sum_{q_i}^{W(i=1...n)} \omega_i q_i$$

with λ_1=0.34, λ_2=-0.33, ω_i is the weighting coefficient set associated with the neighbor points, and inversely proportional to the distance between the centre point p and its neighbours w. This alternating smoothing (step 1) and un-smoothing process (step 2) was shown to preserve the shape more realistically than the conventional Gaussian smoothing filter, as shown in Figure 4(d).

The edema segmentation from section B was projected back to the 3D model according to the MRI slice location, and represented by the volume occupation of individual meshes as in Figure 4(d).

III. EXPERIMENTAL RESULTS

The method was tested on sixteen patients who recently experienced MI. The CMR images were acquired using a 1.5 Tesla MRI machine (scanner: Siemens Avanto 1.5T MRI system) with T_2-weighted ACUTE pulse sequence with normalisation for coil sensitivity: acquisition time 7-12s, matrix 192 x 192, flip angle 180°, echo time (TE) = 1.69 ms, bandwidth = 789 Hz/pixel, echo spacing = 3.4ms, echo train length = 29 and trigger pulse = 2 i.e. alternate heartbeats . The voxel size was 1.9 x 1.9 x 6 mm^3.

Figure 5 shows the segmentation result of one patient from the basal to the apical slice. In order to assess the performance of the proposed edema segmentation algorithm, the automatic edema results are compared with those from a manual segmentation from one expert clinician. Figure 7 illustrates comparative result of automatic quantification versus manual quantification. The comparison shows that the automatic method gives good assessment of edema area when compared with manual delineation, the average area difference for the 7 slices is approximately 7% where the highest error occurs on the second slice.

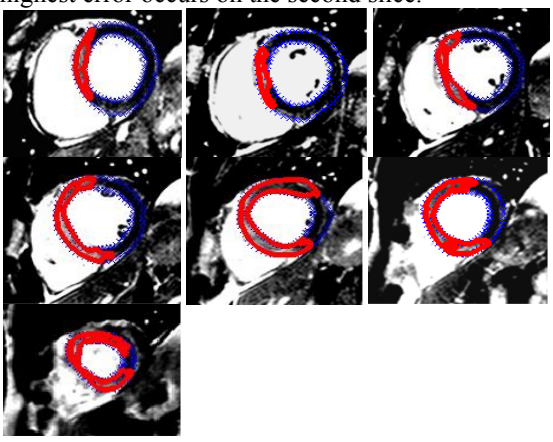


Figure 5: Result of the segmentation on a single patient from Basal to apical

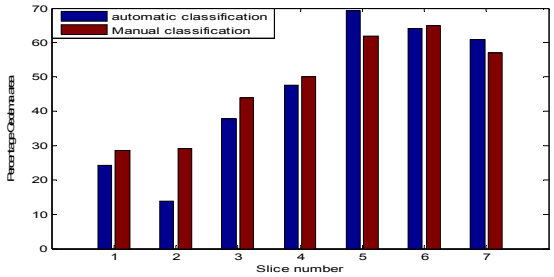


Figure 6: Comparison of automatic quantification versus manual quantification for a single patient

Table 1: Comparison of automatic method with manual segmentation of edema

Measure	Our method	2SD
Mean error	9.95± 3.90%	10.67 ±5.05%

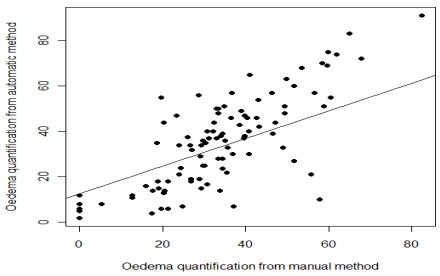
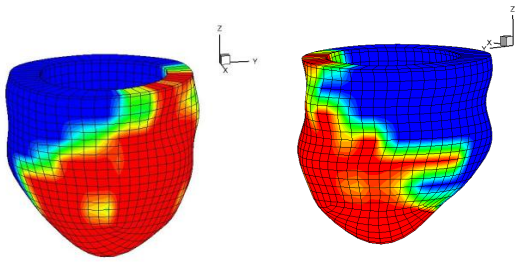


Figure 7 Scatterplot of edema quantification by manual and auto segmentation

Table 1 shows the mean difference of the automatic method compared to the manual method with 98 MRI slices from 16 patients. The results of the proposed method is very encouraging with an average error of 9.95 when compared to the manual classification which is in better agreement with the manual segmentation compared to simple thresholding method of 2SD, which threshold the LV wall intensity above 2 above the normal LV wall tissues intensity. Figure 7 shows the scatterplot of the edema quantification. The linear correlation analysis showed that the two measurements were significantly correlated with R=0.76 ($p<0.05$).

3D view of the LV wall showing the edema region aims to enhance the clinician understanding of the abnormal area with respect to the LV wall. Figure 8(a) and 8(b) presents the edema distribution in the whole LV wall according to the percentage of edema with different views for one patient. From figure 8, the edema region is seen to be very irregular in the LV surface, especially in Figure 8(b) where a penetration of edema region is shown inside the normal myocardial tissue. The irregular occupation of edema region inside normal tissue might be beneficial during recovery process, while a greater number of studies are needed for quantifying edema distribution pattern. The volume ratio of edema region for the patient is 47.37%, nearly half of the LV wall.



(a) (b)

Figure 8: 3D view of LV wall showing normal area and edema area

IV. CONCLUSION

In this paper a novel fully automated edema quantification method with 3D visualisation capability was presented. The method employs constraint variational level set to automatically segment the LV wall and then automatically set threshold value for edema delineation. The advantages of the algorithm lie in its ability to automatically segment the LV wall and the edema area with the capability to include signal void area within the edema area. Another advantage of the algorithm is in its 3D quantifying and visualisation capabilities which will be beneficial for clinicians in understanding the edema region within the LV wall. Experiment with 98 slices of SA images from sixteen patients demonstrates the method gives excellent segmentation and quantification results compared to manual segmentation.

ACKNOWLEDGMENT

The author would like to thank Golden Jubilee National Hospital, Glasgow for providing the MR images used in this study

REFERENCES

[1] P Kellman, A.H. Aletras, C Mancini , E.R . Mcveigh, A.E Arai, "T2-prepared SSFP improves diagnostic confidence in edema imaging in acute myocardial infarction compare to turbo spin echo". *Magn Reson Med.* vol 57, pp. 891-897, 2007.

[2] Jordin, D.G, James RC, Jacqueline AF, Matthias GF. Single- short steady-state free precession can detect myocardial edema in patients: A feasibility study. J of Mag Reson Imaging 2009; 30:690-695.

[3] H. Abdel-Aty, A. Zagrosek, J. Schulz-Menger, A. Taylor, D. Messroghli, A. Kumar, M. Gross, R. Dietz, and M. Friedrich, "Delayed enhancement and T2-weighted cardiovascular magnetic resonance imaging differentiate acute from chronic myocardial infarction," *Circulation,* vol. 109, pp. 2411 - 2416, 2004.

[4] G. Stalidis, N. Maglaveras, A. Dimitriadis, C. Pappas, and M. Strintzis, "Detection and modeling of infarcted myocardium regions in MRI images using a contour deformable model," in *Computers in Cardiology 1995*, 1995, pp. 17-20.

[5] DP Regan, Rizwan A, Clare N, Yvonne T, Giuliana D. Cardiac MRI of myocardial salvage at the peri-infarct border zones after primary coronary intervention. Am J Physiol Heart Circ Physiol 2009; 297: H340–H346.

[6] K. Elagouni, C. Ciofolo-Veit, and B. Mory, "Automatic segmentation of pathological tissues in cardiac MRI," in *Biomedical Imaging: From Nano to Macro, 2010 IEEE International Symposium on*, 2010, pp. 472-475.

[7] L. Vincent, "Morphological grayscale reconstruction in image analysis: application and efficient algorithm," *IEEE Transaction on Image Processing*, 1993. 2(2): pp 176-201.

[8] K. Kadir, A. Payne, J. Soraghan, and C. Berry, "Automatic Left Ventricle Segmentation in T2 Weighted CMR Images," in *Image Processing and Communications Challenges 2*. vol. 84, ed: Springer Berlin / Heidelberg, pp. 247-254, 2010

[9] Kushsairy Kadir, Hao Gao, Alex Payne, John Soraghan and Collin Berry," Variational Level Set Method with Shape Constraint and Application to Edema Cardiac Magnetic Resonance Image," *DSP 2011*, (to be presented at) DSP2011, Corfu, Greece,2011

[10] K. Kadir, A. Payne, J. J. Soraghan, and C. Berry, "Automatic Quantification of Edema from T2 Weighted CMR Image using a Hybrid Thresholding Edema Sizing Algorithm (HTOSA)," Computing in Cardiology, Belfast, United Kingdom, 2010.

[11] L.-Y. Hsu, A. Natanzon, P. Kellman, G. A. Hirsch, A. H. Aletras, and A. E. Arai, "Quantitative myocardial infarction on delayed enhancement MRI. Part I: Animal validation of an automated feature analysis and combined thresholding infarct sizing algorithm," *Journal of Magnetic Resonance Imaging,* vol. 23, pp. 298-308, 2006.

[12] D. Terzopoulos and D. Metaxas. Dynamic 3D models with local and global deformations: Deformable superquadrics. IEEE Transactions on Pattern Analysis and Machine Intelligence, 13(17), 1991