Automatic Quantification of Oedema from T2 Weighted CMR Image using a Hybrid Thresholding Oedema Sizing Algorithm (HTOSA)

K Kadir [1, 3], A Payne[2], John J Soraghan [1], C Berry [2]

[1]Centre for excellence in Signal and Image Processing, Dept of Electronic and Electrical, University of Strathcylde, UK
[2]Faculty of Medicine, BHF Cardiovascular Research Centre, University of Glasgow, UK
[3]Department Of Electrical Engineering, UniKL BMI, Malaysia

Abstract

Oedema is fluid retention within the myocardial tissue due to damage tissue causing swelling in the affected area after myocardial infarction (MI). Quantification of oedema area after an MI is an important step in medical prognosis to differentiate between viable and death myocardial tissue. In this paper a novel technique of Hybrid Thresholding Oedema Sizing Algorithm (HTOSA) is presented. To quantify the oedema a hybrid technique based on combination of morphological operation combined with statistical thresholding is used. The performance of the method was tested on real T2 weighted MRI data. The quantitative result of the automatic method compare to manual segmentation by a skill clinician is very encouraging with correlation score of 81.1%.

1. Introduction

Myocardial Infarction (MI) is one of the major cardiac diseases. 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). After MI, myocardial water content is retained within the myocardial tissue due to damage tissue causing swelling in the affected area of myocardial and it is know as oedema. The oedema appears as a relatively bright area compare to the normal myocardial tissue as shown is Fig 1. Since the recovery of myocardial is directly related to the extent of oedema, it is important to quantify the oedema after the MI. Several studies have been carried out that shows T2 weighted Cardiac Magnetic Resonance (CMR) image enables the visualisation of normal area and oedema area [1], [2].

Quantification of oedema size is normally performed using manual contouring where an expert clinician will manually delineate the oedema area. Major challenges in automatic quantification of oedema are the weak edge information on epicardium boundary and the present of signal void due to myocardial haemorrhage. This area of signal void is usually included into the oedema area by the clinician, but the difficulty is the area has different tissue characteristic compare to the oedema.

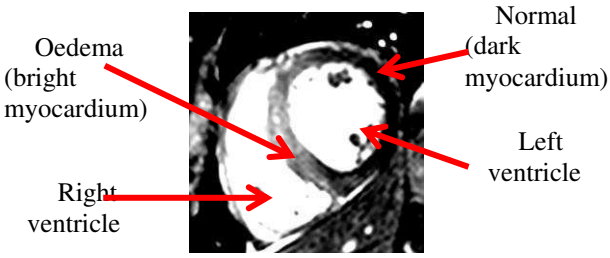

Figure 1: Short axis T2-weighted image

To speed up the quantification of oedema several semi automatic methods used simple intensity thresholding based on the standard deviation (SD) method. The most commonly used is 2SD or 3SD above the mean or normal myocardial intensity [3], [4]. All the above method required the user to select normal region or oedema region for setting up the threshold value. O'Regan et al [5] proposed using level set algorithm to segment the oedema area, the weakness of this method is that it require and expert to first define the oedema boundary before the level set generate single continuous region.

In this paper we present a fully automatic oedema quantification method where the threshold is automatically set based from image intensity information and the used of feature analysis to eliminate spurious small positive bright object on the Left ventricle (LV) wall and to compensate dark area of signal void.

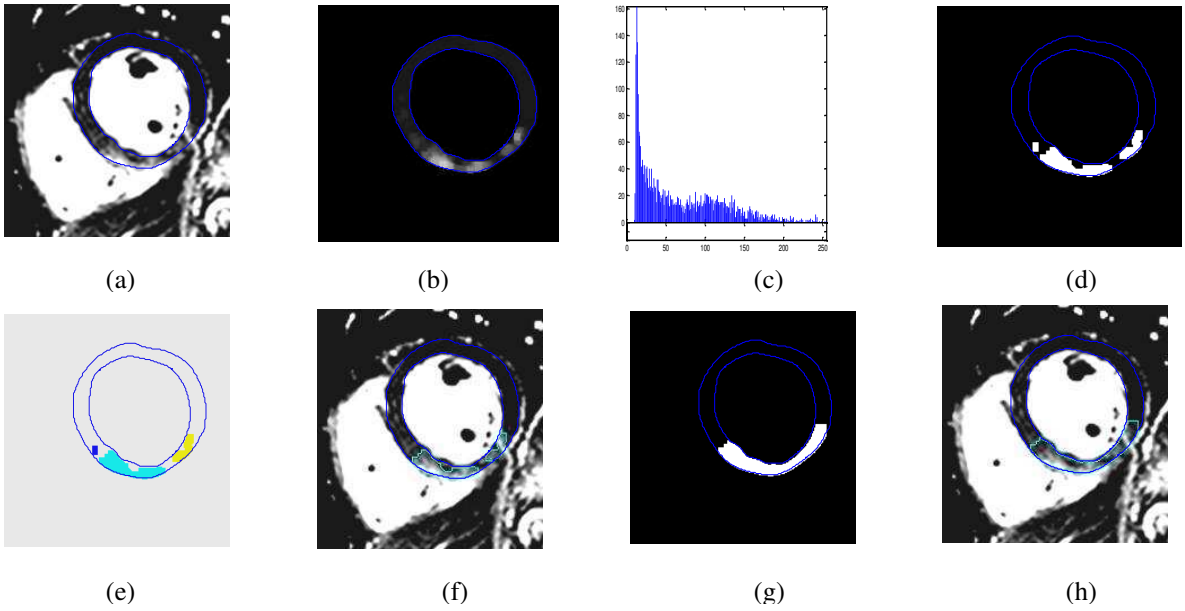

Figure 2: (a) Left ventricle (LV) contour, (b) Intensity histogram, (c) Pre-processed image (d) 2 SD threshold, (e) Region labelling, (f) Segmented region before signal void inclusion, (g) Signal void inclusion, (h) Final oedema contour

2. Classification and segmentation

In this section a detailed discussion on the proposed system is presented. Figure 2 illustrates how the Hybrid Thresholding Oedema Sizing Algorithm (HTOSA) applied to a series of pre-determined processes to automatically calculate intensity thresholds, performs classification of normal and oedema tissues and exclude spurious small positive bright object on the myocardial wall. Additional post-processing is then applied to include dark pixel region that may account for area of signal void.

2.1. Myocardial boundary segmentation

The first step of the system is the segmentation of myocardial boundary. For all images the myocardial boundaries are automatically segmented by the method presented in [6]. In this paper we present a technique of using fuzzy multi resolution based algorithm to segment the myocardial boundary. The method takes multi-slice T2 weighted CMR images (an MRI data stack) from the basal to the apex of the heart. Inter-slice and intra-slice fuzzy reasoning is used to guide the centre point detection for each slice. Morphological filtering is used in the reconstruction to homogenise the blood pool region. Then a radial search Fuzzy Multiscale Edge Detection (FMED) is used to segment the endocardial and the epicardial of the LV.

2.2. Image morphological operation

The presence of small bright areas in the myocardial wall increases the difficulty of accurately classifying oedema tissue. To reduce the false positive level, morphological filtering is employed that uses an opening operation with a disk shape structuring element used to remove small spurious bright regions as in figure 2(b). All bright region having a radius of less than 5 pixels are removed from the myocardial wall. The myocardial wall is then left with bigger bright region which are most probably oedema areas.

2.3. 2SD Thresholding

The mean and SD of the normal tissue intensities are first estimated by the maximum value of the lower part of the intensity histogram [7] as illustrated in figure 2(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 2(d). The remaining bright areas are then labelled as seen in figure 2(e) and the size of the bright areas calculated. Areas below a certain threshold which is empirically set are removed. The final bright areas are the then classify as oedema region.

2.4. Inclusion of signal void areas

Additional post processing is applied to check the presence of signal void area within the myocardial wall. An iterative dilation process is performed to connect the remaining bright area of the oedema and to include signal void area within the oedema area.

The steps for iterative dilation are:

```
if Oedema area > 1
    counter=1
        for counter = 1:max iteration
            Image dilate=dilate(Image initial)
        end
    Image final= image dilate< image myocardial wall
else
    do nothing
end
```

Next the remaining isolated dark pixels are analysed. Each dark pixel is reclassified as oedema if its border is completely surrounded by the oedema area and within the myocardial wall using a morphological reconstruction algorithm [8]. In figure 2(f) initial oedema contour where the algorithm failed to take into account dark pixel region in between the two oedema areas. The iterative dilation is performed as in figure 4(g) to connect the two regions together and finally in figure 4(h) final oedema contour is shown.

3. Experimental results

In the experiment CMR images from eight patients who recently experienced myocardial infarction (MI) which were acquired using a 1.5 Tesla MRI machine (scanner: Siemens Avanto 1.5T MRI system) are used. For each patient, between nine to twelve slices of T2 weighted MR images were acquired. All short axis (SA) images are used except for the extreme basal slice which contain both ventricular and atrial myocardium and apical slice because of the difficulties due to the large partial volume effect of dense trabeculae carneae [9].

Figure 3 illustrates comparative result of automatic classification versus manual classification for a single patient. The result shows the automatic method gives good classification of oedema area when compared to the manual classification. Table 1 shows the mean error of the automatic method compared to the manual method for eight patients. The result of the propose method is very encouraging with an average error of 9.34% when compared to the manual classification. From Table 1 the anomaly result is for patient8. There are two reasons for this (i) the presence of significant signal void areas in one of the slices which takes up lot of the oedema area thus the system underestimates the particular slice and (ii) the problem with the most distal slice with increase signal intensity that creates 'apparent oedema' in the distal lateral wall.

Linear correlation analysis is done for the automatic classification and from the correlation result as shown in figure 4 a good correlation is obtained by the propose method with a correlation factor of 81.1%.

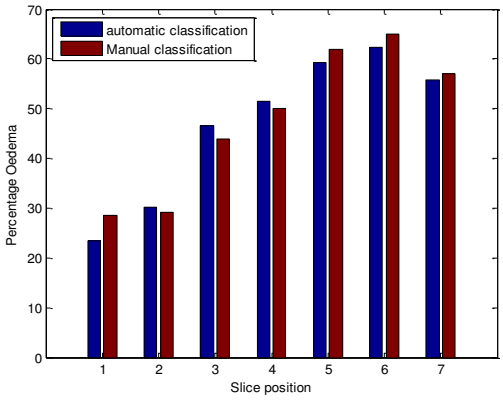

Figure 3: Comparison of automatic classification versus manual classification for a single patient

Table 1: error between automatic versus manual

Patient	Mean error
Patient1	2.57
Patient2	5.65
Patient3	6.51
Patient4	12.89
Patient5	11.94
Patient6	7.44
Patient7	10.05
Patient8	17.64
Average	9.34

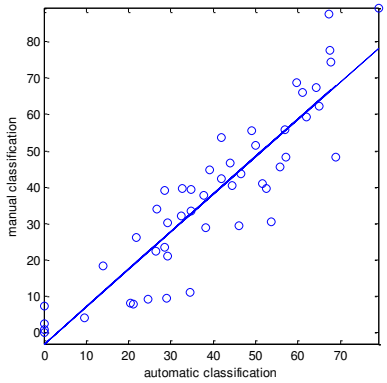

Figure 4: Linear regression analysis with correlation of 81.1%

4. Conclusion

In this paper a new automatic method for oedema segmentation and quantification was presented. The results compare favourably to manual analysis by an expert clinician. The advantages of the proposed method lies in its ability to automatically set a threshold value for the classification of oedema and its ability to include

signal void area within the oedema area. This is beneficial to clinician as it reduces the amount of time required to segment and analyse the oedema area from CMR images.

Acknowledgements

The author would like to thank Golden Jubilee National Hospital, Glasgow for providing the CMR images and also with Majlis Amanah Rakyat (MARA) without the financial support the study would not be possible.

References

[1] Peter K, Anthony HA, Christine M, Elliot RMc, Andrew EA. T2-prepared SSFP improves diagnostic confidence in edema imaging in acute myocardial infarction compared to turbo spin echo. Mag Reson Med 2007; 891-897

[2] Shiravman G, Yiu CC, Ali M, Georgeta M, Sanjay R, Subha VR, Orlando PS. T2 quantification for improved detection of myocardial oedema. J of Cardio Magnetic Resonance 2009; 11:56

[3] 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.

[4] Abdel-Aty, H., et al., Delayed Enhancement and T2-Weighted Cardiovascular Magnetic Resonance Imaging Differentiate Acute From Chronic Myocardial Infarction. 2004. p. 2411-2416.

[5] Declan P O'R, 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] Kushsairy K, Alex P, John S, and Colin B. Automatic Left Ventricle Segmentation in T2 Weighted CMR Images, 2nd International conference in Image Processing and Communication, 2010

[7] Li YH, Alex N, Peter K, Glen AH, Anthony HA, Andrew EA. Quantitative myocardial infarction on delayed enhancement MRI:. Part1: Animal validation of an Automatic Feature Analysis and Combined Thresholding Infarct Sizing Algorithm. J of Mag Reson Imaging 2006; 23:298-308

[8] Soille P., Morphological Image Analysis: Principles and Applications. 1999: Springer Verlag. 173-174.

[9] Pednekar A.,Kakadiaris I. A., Kurkure U.,Muthupillai R., and Flamm S., Validation of the Automatic Computation of the Ejection Fraction from Cine-MRI, Medical Image Computing and Computer-Assisted Intervention – MICCAI, Springer Berlin / Heidelberg 2003; 2879: 987-989

Address for correspondence.
Name. Kushsairy Abdul Kadir
Full postal address. CesiP, Department of Electronic and Electrical Engineering, University of Strathcylde,
Royal College Building, 204 George Street, Glasgow
G1 1XW, UK
E-mail address. kushsairy@eee.strath.ac.uk