The Segmentation of Lumen Boundaries at Intravascular Ultrasound Images Using Fuzzy Approach

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Abstract

The segmentation of the lumen in intravascular images (IVUS) of the coronary artery is the first step for the evaluation of the morphology of the vessel under analysis and the detection of possible atherosclerotic lesions. In this paper, the segmentation of lumen boundaries at intravascular ultrasound images using fuzzy approach is investigated. In order to diagnose lumen boundaries at IVUS, the noise of images are removed using median filter and also spatial filters in polar coordinates are employed with the purpose of identifying and removing the catheter. In the processing step using two fragmentation algorithm based on Integration i.e. FCM and RHMF and at the same time using a boundary detection algorithm based on tissue leads to finding a more accurate initial guess about the boundaries, then in the second step using approximations that are based on RBF results in improving boundary detection and also decreasing fault detections. The simulation results showed the effectiveness of proposed method with 86.06% of accuracy.

Keywords: Lumen Fragmentation, Intravascular ultrasound, FCM Algorithm, RBF Algorithm

Introduction

Statistical methods generally are based on the assumption that the grayscale of intensity related to lumen and plaque regions are generated by reflectors with two different distribution. As a result, there are modelled based upon parametric and nonparametric approaches. Authors in (Dos Santos Filho E, 2006) used this assumption to design an algorithm based on regions in order to detect lumen boundaries through image thresholding in polar coordinates. Then, in Cartesian coordinates and by considering an oval shape boundaries are automatically extracted. Changing the threshold level in each level of thresholding is used with the aim of detecting boundaries of MA (Katouzian A, 2012). Moreover, in (Taki A, 2008) an algorithms is presented with the purpose of extracting lumen boundaries and MA[1] simultaneously, which first employs time-invariant different filters and then speckle is removed and finally two different threshold level to detect boundaries are utilized. If distributions corresponding to lumen and tissual regions are separated appropriately, boundaries of arteries will find with high accuracy using decorrelation operator, simple thresholding methods, unsupervised classification algorithms and morphological operators (Rafael C. Gonzalez, 2006), (Katouzian A, 2012). Although these algorithms are very simple from the point of computational implementation, the valuable results are derived when low-frequency transducers (20-30 MHz) are utilized for imaging techniques. Furthermore, authors in (Katouzian A, 2012) utilized Rayleigh distribution assumption and complete information about appearance of speckle to model final counter using initial knowledge and Markov processes, however, it seems that this assumption is not valid in all cases.

Proposed Method

All of the data that is utilized in this study is taken from Volcano website, which is not a free data source. Moreover, the dimension of all images are 512*512 and these images include 11 frames that are related to 11 different heart. Also, we employed a radiologist with the purpose of detecting accurate boundaries, which his name is Dr Mohammad Mehdi Kadivar. It is to be noted that the frequency of images is 4MHz. A sample of utilized image is shown in figure 1:

[1] Media advantage

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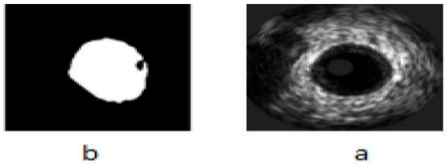

Figure 1: Original image (a) and image with detected boundary (b)

Considering the fact that the accurate detection of lumen boundaries and also plaque boundaries is very important, novel algorithms should design in such a way that increases accuracy and decreases fault in the process of boundary detection. In this study, with the purpose of increasing accuracy in boundary detection firstly, in preprocessing step median filter is utilized to remove speckle noise from the image, then to identify and remove catheter spatial filters in polar coordinates are employed. In the processing step using two fragmentation algorithm based on Integration i.e. FCM[2] an RHMF[3] and at the same time using a boundary detection algorithm based on tissue leads to finding a more accurate initial guess about the boundaries, then in the second step using approximations that are based on RBF results in improving boundary detection and also decreasing fault detections. Moreover, FCM algorithm is employed with the aim of converting images into two clusters, which are related to regions inside and outside the lumen. Furthermore, using RHMF algorithm, which is an algorithms to detect object in image, to find an object in the image leads to finding the output of FCM on original image and consequently the largest detected area is identified as a lumen area.

Simultaneously DWT is used in order to detect boundaries in image and a special boundary is detected with this method afterwards, using RBF results in creating an approximation between two boundaries so that the final boundary could achieved. The final boundary is compared with the one that suggested by the radiologist. The flowchart of proposed algorithms is shown in figure 2:

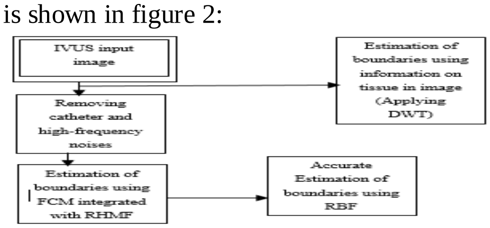

Figure 2: Flowchart of proposed method

It is to be noted that there are a lot of problems in segmentation of ultrasound images, therefore, one of the most important parts in segmentation of IVUS is the preprocessing step and without it these images do not have any concept. The preprocessing step includes 4 parts, removing the shadow of catheter from IVUS images, identifying luminous rings in these images, removing speckle noise and the increase in image contrast. A detailed description of preprocessing step is shown in figure 2.

Applying FCM Algorithms

The main assumption is that the intensity related to lumen and other regions are generated by reflectors with two different distribution (Araki T, 2015) and consequently they can be segmented into two regions using fuzzy algorithms. Therefore, proposed algorithm utilized intensity of pixels with the purpose of clustering and finally the output of this method divide into two images, which are related to lumen and other regions. The main difficulty in this method is the lack of accurate boundary. The output result of this method is a matrix with the dimension of 512*512*3, which the probability of belonging to each cluster is determined through it. The result of this part is shown in figure 3.

Figure 3: Detected boundary using FCM

Extracting boundary using Object finder filter

Each pixel belongs to the region that has the most of membership belonging. Counting the number of zeros is done in 5 regions including top right, top left, bottom right, bottom left and middle region. All the pixels that are less than threshold value are removed in this pattern. Then, the largest regions of zero in original image is considered as the lumen area. The results of this operation is shown in figure 4.

[2] Robust high-order matched filter

[3] Fuzzy C-means

Figure 4: The results of using FCM+RHMF algorithm

Estimation of boundary using wavelet

The main assumption is that the advantage of spectral analysis or expansion of position-frequency and their generalization to wavelet spaces are used with the aim of detecting tissual lumen pattern in IVUS (Katouzian A B. B., 2008). In order to implement this algorithm first of all the image is transferred to polar coordinates and then Haar wavelet is utilized with the purpose of detecting lumen boundaries. Lemarie–Battle that is a diagonal filter is applied to the images and the push of complex coefficients is extracted as the feature. Two levels of decomposition are utilized in order to achieve these features. Spline interpolation in the direction of the nearest clear edge set and also in the radial direction is utilized with the purpose of extracting continuous boundary.

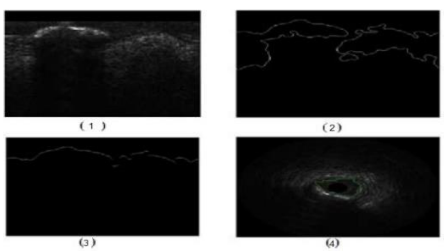

Figure 5: (1) The image in polar coordinates, (2) highlighted boundary, (3) the nearest clear edge boundary and (4) detected boundary in original image

The final evaluation of lumen boundary

For the purpose of final evaluation RBF radial functions are utilized to interpolate in specified boundaries using DWT and FCM. It is to be noted that the accuracy parameter is considered using the proposed algorithm and the radiologist's comments, which is as follows:

$$Accuracy= \frac{The\ number\ of\ desired\ counter\ Located\ on\ boundaries}{The\ number\ of\ total\ counter} * 100$$

In table 1 the results of ROC curve is shown, which is as follows:

Table 1: The results of ROC curve

Image number	The number of learning step	The speed of response (s)	Accuracy
1	100	60	83.14
2	105	64	81.86
3	85	54	84.85
4	101	60	94.59
5	106	65	93.39
6	98	60	80.91
7	99	59	75.92
8	96	58	88.22
9	94	54	82.88
10	92	51	84.85
11	108	68	94.86
Mean	99	59.36	86.02

Furthermore, in figure 6 the probability of detection to false alarm rate is plotted, which is as follows:

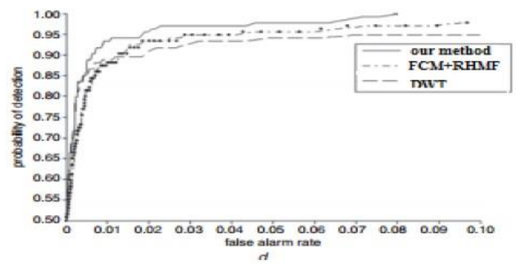

Figure 6: The Results of ROC curve

Moreover, the results of detected boundary for 6 images is collected in figure 7, which represents the small differences between the radiologist's comment and detected boundary using proposed algorithm.

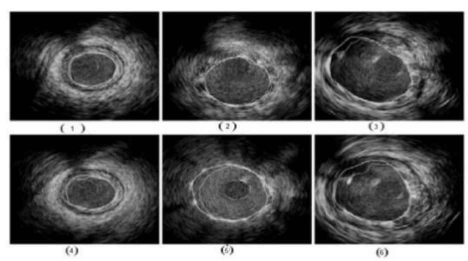

Figure 7: Detected boundary for 6 images

Finally, the results of using proposed method is shown in table 2, which is as follows:

Table 2: The results of using proposed method

Parameter	Formable model method	The proposed algorithm
Accuracy in percent	85	86.02

Conclusion

In the preprocessing part median filter with the aim of removing noise of IVUS images had the best performance in comparison with other method i.e. Butterworth filter and wavelet analysis. This issue is confirmed using the value of PSNR[4] after removing noise of image. The performance of contrast enhancement using histogram equalization heavily affects the membership functions of pixels and Otsu thresholding. Therefore, it is omitted in preprocessing part of proposed approach. Removing the effects of catheter after applying fuzzy approach to the image leads to converting image into two cluster, which one of them has the fewest central pixel and is related to lumen. Moreover, using a pattern recognition algorithm for image and also FCM boundary of lumen in original image is extracted. The results of ROC curve showed that combination of FCM and wavelet has the better performance in comparison with using each method alone. Moreover, the time related to running of program was acceptable and was about only 1 minute. Removing speckle noise is done after extracting levels of Otsu. The main reason was that the regions in image were softened and the performance of thresholding did not have the appropriate results. Furthermore, it is to be noted that the results of using FCM algorithm is about 86.02%, which has the better performance in comparison with other methods. The identification algorithm of shadow showed the small error with the aim of detecting regions. It should be noted that the image processing of IVUS heavily depends upon the steps in preprocessing part. Therefore, it is strongly recommended that more intelligent algorithms designed for different part of image. Employing adaptive methods leads to performing contrast enhancement operation in such a way that fuzzy information of pixels will preserve.

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[4] Peak signal-to-noise ratio