**Fully Automated lumen detection in intravascular OCT images by using fuzzy system**

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Abstract

Intracoronary optical coherence tomography (OCT) is a catheter based medical imaging technique that provide high resolution imaging of coronary lumen structures. However these images affected by catheter and stents shadows during pullback procedure. In order to overcome this problem, we present a new approach to detect the lumen boundary automatically using fuzzy system. At the first, the OCT images are mapped into the normalized polar OCT (NPOCT) space, and then primal lumen boundary is estimated by image processing methods. Afterwards, lumen boundary is detected by a fuzzy system precisely. Finally the results are remapped into the OCT image space. The proposed approach is compared with manual lumen detection (MLD), and HD and AD distance results are obtained.

1. Introduction

OCT imaging technique provides high resolution cross-sectional images from coronary arteries. These images have detailed morphological information about vessel layers, stents and plaques [1]. During catheter pullback procedure thousands frames achieved from artery. To evaluate the vessel information these frames must be segmented. This is a very difficult and time consuming work in manual way. Therefore, for frame analysis, a fast and automatic approach for segmentation is necessary.

To detect the symptoms of coronary diseases like high risk plaques, the lumen should be detected initially. Lumen detection for IVUS imaging modality that is an older technique for imaging coronary arteries is performed in [1,2] but these images have lower quality than OCT images, accordingly, the results have low accuracy [1-4].
So far, the different lumen detection techniques from IVUS-OCT images are reported. The majority of them is based on morphology and some other binary image processing [5-14]. Another set of these methods are based on gray level set and active contour methods like “snake”, that are semi-automatic approaches [15-17].
Catheter and stents shadows in the frames had made serious problems in OCT imaging, ignored in many present lumen detection methods. In this paper, we present a novel, full automatic approach using fuzzy system to detect lumen boundary with the shadow effects.

2. Methods
The flowchart in Figure1 shows OCT image processing framework. The proposed method consists of four steps:
i. OCT images are mapped into new normalized polar domain.
ii. Primal lumen boundary is estimated by binary image processing method.
iii. Next, final lumen boundary is detected by fuzzy system.
iv. In final step, the detected lumen boundary pixels are remapped into OCT image space.
In this approach the fuzzy system is used to correct the detected lumen boundary and reduce shadows effect in the frames.
Fig. 1: The flowchart of proposed approach. Following the mapping frames in NPOCT space, lumen contour is detected.
2.1 NPOCT space mapping

A normalized polar OCT (NPOCT) image representation are used to normalize OCT images and maps them into polar space. Lumen boundary in OCT space images have circular structure and are proper for human visual evaluation. Hence for fast and accurate automatic frame evaluation, the new normalized polar space is needed. In the proposed NPOCT image space, only pixels with more information about vessel wall were mapped to polar coordinate. Figure 2 (a) shows a frame of OCT image and mapped it as NPOCT space is shown in Figure 2(b).

![Figure 2](image_url)

Fig.2: a) The illustration of a frame of OCT image, b) mapped OCT image(a) in NPOCT space.

2.2 Primal lumen boundary estimation

An automatic thresholding on NPOCT space image is used to introduce a new binary space. In binary NPOCT image, primal calculated lumen boundary is corrupted by stent and catheter shadows as shown in Figure 3(a). So, the only thresholding method is not suitable for lumen boundary detection and there are some error in boundary as shown in Figure 3. Thus we estimate the only primal lumen boundary by thresholding method. Figure 3(b) shows the first detected lumen contour consists of false detection in shadows effect locations, red arrows are pointing to this places.

![Figure 3](image_url)

Fig. 3: Primal lumen contour by tresholding method. The red arrows are pointing to errors of tresholding method because of shadows.
As shown in Figure 4, D(x) is calculated for any detected pixels in lumen boundary, that is distance with neighbours pixels. Pixels have been removed if D(x) is greater than a threshold value. In Figure 4 the green pixels show the list of primal lumen boundary pixels.

![Primal detected lumen boundary](image)

Fig. 4: Primal detected lumen boundary

### 2.3 Detecting lumen boundary precisely

Many pixels have been removed in primal lumen boundary list because of the shadows effect. Hence in detecting lumen boundary precisely, to correct detected lumen contour and extrapolate the lumen contour in shadows areas, we used fuzzy system to detect vessel wall completely. As it is shown in Figure 5, fuzzy system estimated lumen location precisely in the shadow area. In this figure green pixels indicate the vessel wall completely without any shadows effect for some other NPOCT space images.

![Lumen contour detection in NPOCT space](image)

Fig. 5: Lumen contour detection in NPOCT space, the green contours are used to indicate the vessel wall without shadows effect.
Fig. 6: The illustration of promising result of proposed lumen detection algorithm for frames which are affected by many shadows.

In different lumen detection techniques lumen was detected without regarding shadows effect, but in the proposed approach, lumen boundary detection is performed precisely in OCT images with more shadows effect. Figure 6 shows detected and estimated lumen boundaries in all of vessel walls accurately with some kind of shadows effect.

2.4 Return to OCT image space

In the final step, the only lumen boundary list in NPOCT are remapped into OCT image space in order to better presentation of lumen boundary and for comparison proposed method with MLD. Some other detected lumen in OCT image are illustrated in Figure 7 by green pixels.
Fig. 7: Typical OCT images and corresponding lumen detection results.

4. Results and discussion

To evaluate results, lumen boundary detected in 24 patient OCT images in four dataset and evaluated by MLD which are shown in Table 1. AD is the average distance between automatic detected lumen and MLD lumen boundary. HD is the Hausdorff distance that is maximum distance between detected lumen and MLD lumen boundary. Very small AD and HD distance indicate the promising operation of proposed approach.

Table 1: Evaluate AD and HD distance by MLD

<table>
<thead>
<tr>
<th>Datasets</th>
<th>AD</th>
<th>HD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dataset 1</td>
<td>0.0271mm</td>
<td>0.0833mm</td>
</tr>
<tr>
<td>Dataset 2</td>
<td>0.0113mm</td>
<td>0.0952mm</td>
</tr>
<tr>
<td>Dataset 3</td>
<td>0.0232mm</td>
<td>0.0791mm</td>
</tr>
<tr>
<td>Dataset 4</td>
<td>0.0302mm</td>
<td>0.0818mm</td>
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</table>

HD and AD distance for proposed method dataset are evaluated by MLD, compared with methods in [6,8,11,16] that are based on FMM-3D PDF, wavelet, helical active contour, active contour method on IVUS-OCT image, respectively. Result has been shown in Table 2.
Table 2: AD and HD distance result in comparison with other methods

<table>
<thead>
<tr>
<th>Methods</th>
<th>AD</th>
<th>HD</th>
</tr>
</thead>
<tbody>
<tr>
<td>FMM-3D PDF</td>
<td>0.069mm</td>
<td>0.201mm</td>
</tr>
<tr>
<td>Wavelet method</td>
<td>0.059mm</td>
<td>0.084mm</td>
</tr>
<tr>
<td>Helical active contour</td>
<td>0.139mm</td>
<td>0.509mm</td>
</tr>
<tr>
<td>Active countor</td>
<td>0.068mm</td>
<td>0.083mm</td>
</tr>
<tr>
<td>Proposed method</td>
<td>0.023mm</td>
<td>0.084mm</td>
</tr>
</tbody>
</table>

In the proposed method the average AD and HD distance is 0.023mm and 0.084mm respectively, for given dataset. In comparison with other methods, our approach achieved high accuracy rate.

5. Conclusions

In this study, a new fully automatic, accurate and fast approach was proposed for estimate lumen boundary location which is used fuzzy system. The proposed method estimates lumen boundary in areas that affected by shadows and detected total lumen bound precisely. For given dataset proposed approach and other methods are evaluated by MLD and in comparison with other methods, very small AD and HD results shows higher accuracy of proposed approach.

References


[10] Sihan, K., Botha, C., Post, F., de Winter, S., Regar, E., Serruys, P. J., ... & Bruining, N. Fully automated gating of optical coherence tomography data. In *Computing in Cardiology, 2010; 9-12.*


