Automatic Segmentation of Intravascular Ultrasound Images based on Temporal Texture Analysis

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Abstract

In our study we developed a novel automatic algorithm for the analysis and delineation of lumen and external elastic membrane (EEM) boundaries using both temporal and spatial variation of IVUS data. The pre-processing steps involve the construction of Laplacian gradient image from neighboring images, and the use of discrete wavelet frame decompositions for texture computation. A smooth Lumen and EEM contour is predicted by applying radial basis functions on contour initialization. This algorithm is evaluated on large data set of multi-patient 2293 IVUS images and pitted against the manually segmented contours by medical experts. It is observed that this algorithm reliably performs contour prediction with clinically appreciated limits of average prediction error equaling 0.1254 mm and 0.0762 mm for Lumen and EEM respectively. Furthermore a custom Lumen detection algorithm for stented images is proposed and tested with average prediction error of 0.048 mm

1. Introduction

In a typical IVUS image, the lumen is a dark echo-free area adjacent to the imaging catheter and the coronary artery vessel wall mainly appears in three layers: Intima, Media, and Adventitia (Fig. 1). As the two inner layers are of principal concern in clinical research, segmentation of IVUS images necessary to isolate the intima-media and lumen which provides important information about the degree of vessel obstruction as well as the shape and size of plaques. Such segmentation can be performed manually. There are several factors (artifacts) that significantly reduce the accuracy of segmentation and ultimately cause difficulty in interpretation: the ever present speckle noises in the ultrasonic images and particularly on human tissues, Guide wire with reverberation, reflection from sheath surrounding transducer, barely identifiable lumen intima boundary, EEM-like features beyond EEM and bright echo from vessel wall being close to transducer, etc.

There has been a large amount of effort made including the use of automated contours models for the 2D and 3D IVUS segmentation in recent years (see e.g. [1-12]). In this paper we will present an automated segmentation method making use of both temporal and spatial information and the discrete wave frame decomposition to extract the texture information and for initialization of contours. The radial basis function is used to construct the final contours in a few iterative steps. The proposed method is tested in a large data base provided by the Brigham and Women Hospital in Boston with very encouraging results [13].

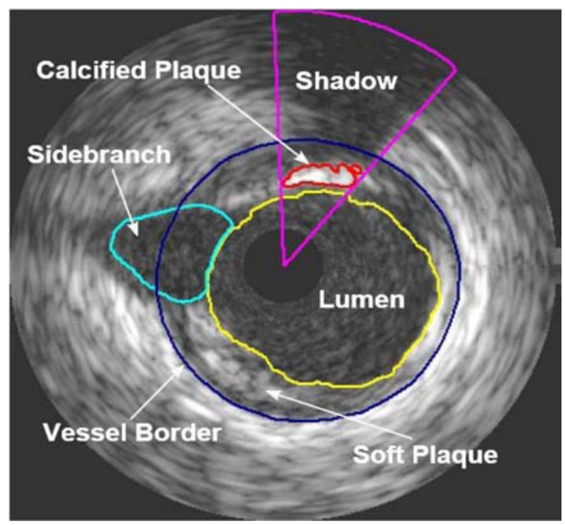

Fig 1. .Typical 2D Cross-sectional view of coronary artery obtained by IVUS methodology. It highlights the critical lumen and vessel border areas.

2. The database

The original 2D cross sectional images obtained from IVUS sensor as provided by Brigham Women Hospital for our academic research is in envelop file format. They are converted into PC-Matlab format with 256x256 pixels in polar format. There are 15 pull-out sequences from 9 patients. There are a total of 2293 gated image frames which have been manually segmented and are useful for training and validation purposes. A total of 57098 image frames provides us a large data set for algorithm testing. Although many studies on IVUS image segmentation have been conducted with different but limited amount of success, none has employed such a large data base. We believe IVUS image segmentation is a problem in pattern recognition and computer vision. Considering the successes of many pattern recognition and computer vision problems in the last 50 years and their great impact on modern society, we are confident that an effective automated segmentation process can be developed as proven in this paper.

3. The proposed method

It is proposed to start with the Temporal IVUS.

Image correction. Obtaining temporal Laplacian image gradient on basis of the four-image neighborhood does noise correction. The idea is that the motion of cells around the arterial wall is faster over time when compared to the change in noise artifices between successive IVUS frames. In the next stage we will be tracking the lumen wall. The lumen wall in IVUS images shows significant high frequency variation i.e. fine texture around Lumen. In certain images due to the catheter induced artifacts and the guide wire shadow there is significant intensity variation around Lumen too. For media-adventitia, texture variation around wall is smooth or coarse. There is significant intensity variation too around this wall, due to its properties and catheter induced artifacts. Thus we can use this texture and intensity information combined to trace the two contours. The proposed method makes use of a composite operator that depends both on texture and temporal variation of intensity. Lumen contour can be traced based on finest texture and intensity specifics. Once we have the contour of lumen border we get the media-adventitia border by finding the coarse-most texture located outside the lumen border. Once this information of the two contour initializations is obtained we can use Low pass filtering / 2D Radial basis functions to obtain smooth 2D contours. The detailed procedures involve the steps of: 1) pre-processing that removes catheter induced artifacts, 2) noise correction by temporal analysis that takes the gradient of the five frames including the current frame at each pixel, 3) gating the intensity and texture information. 4) Lumen border contour initialization, 5) tracing media-adventitia initialization, and 6) obtaining smooth contours with radial basis functions.

Now in Step 3, the discrete wavelet decomposition (DWD) is used for detecting and characterizing texture properties in the neighborhood of each pixel. This is a method similar to the discrete wavelet transform (DWT) that uses a filter bank to decompose the grayscale image to a set of sub-bands. The main difference between DWT and DWF is that in the latter the output of the filter bank is not subsampled. The DWF approach has been shown to decrease the variability of the estimated texture features, thus improving pixel classification for the purpose of image segmentation. Fig. 2 is a comparison before and after applying Radial Basis Function (RBF). .

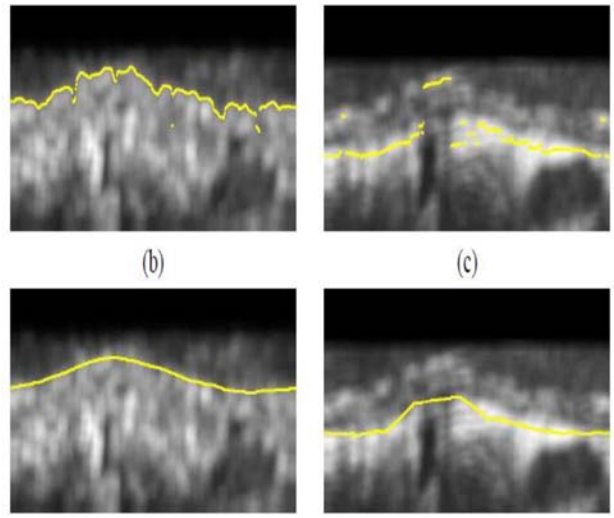

Fig 2. Lumen (b) and media/adventitia (c) contours before (upper) and after (lower) applying RBF.

4. Implementation and results

.The above-proposed methodology is implemented on all 2293 images on the MATLAB platform. The algorithm takes 0.07 seconds to work with a single image and gives out the contours. The manual segmented data is for gated frames only. The objective of this research is to segment the Lumen and EEM. The benchmarking of these results is done against the manual segmentation results. Fig. 3 shows a comparison between manual and predicted (automated) segmentation results in different colors: Blue for Manual segmented Lumen, Yellow for predicted Lumen, Red for Manual segmented EEM, and Green for predicted EEM.

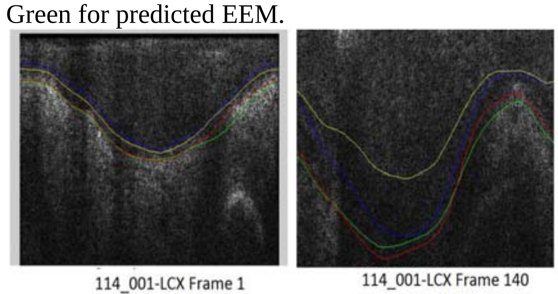

Fig 3. A comparison of manual and predicted segmentation results.

Similar analysis is run on the each of 2293 images For each patient data average error is calculated by averaging the error in pixels between corresponding points of Manual and Predicted contours for each gated frame and these values of respective patient are plotted together. Similarly maximum errors for each frame can also be plotted. By working with the entire data base described earlier, and with the use of 5 consecutive images, Lumen could be predicted with a error of 6.9566 ±2.2144 pixels corresponding to 0.1254 ±0.04121 mm. EEM could be predicted with a error of 4.1915 ±2.3017 pixels corresponding to 0.0762 ±0.04514 mm. This is a remarkable improvement over the use of single image only that has an estimated error of 0.25 mm. For stented images our method has a reported average prediction error of 0.048 mm.

5. Concluding remarks

A novel algorithm has been proposed to auto-detect the Lumen and EEM and it is observed that this algorithm reliably performs contour prediction with clinically appreciated limits of average prediction error under 0.13 mm. The proposed approach does not require manual initialization of the contours, which is a common requirement of several other prior approaches to IVUS image segmentation.

.The experiments conducted with the combination of temporal analysis, contour initialization and contour refinement methods proposed in this work demonstrated the usefulness of the employed texture features for IVUS image analysis as well as the contribution of the approximation technique based on Radial Basis Functions to the overall analysis outcome. The comparative evaluation of the different alternate approaches revealed that use of the temporal texture based initialization and the 2D RBF-based approximation results in a reliable and quick IVUS segmentation, comparable to the manual segmentation and other alternate segmentation algorithms.

.Our automated segmentation algorithm has several clinical applications. It could facilitate plaque morphometric analysis i.e. planimetric, volumetric and wall thickness calculations, contributing to rapid, and potentially on-site, decision-making. Similarly, our method could be utilized for the evaluation of plaque progression or regression in serial studies investigating the effect of drugs in atherosclerosis.

.Based on the results at branched and stented region and increase in accuracy with modified Texture based dilation method targeted to stented IVUS images, it is recommended that we have a stent, branch or normal IVUS image detector first and then have customized texture based algorithm to detect contours in each of these regions.

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