

Segmentation method of intravascular ultrasound images of human coronary arteries



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ABSTRACT

The goal of this study was to show the feasibility of a 2D segmentation fast-marching method (FMM) in the context of intravascular ultrasound (IVUS) imaging of coronary arteries. The original FMM speed function combines gradient-based contour information and region information, that is the gray level probability density functions of the vessel structures, that takes into account the variability in appearance of the tissues and the lumen in IVUS images acquired at 40 MHz. Experimental results on 38 in vivo IVUS sequences yielded mean point-to-point distances between detected vessel wall boundaries and manual validation contours below 0.11 mm, and Hausdorff distances below 0.33 mm, as evaluated on 3207 images. The proposed method proved to be robust in taking into account various artifacts in ultrasound images: partial shadowing due to calcium inclusions within the plaque, side branches adjacent to the main artery to segment, the presence of a stent, injection of contrast agent or dissection, as tested on 209 images presenting such artifacts.

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1. Introduction

Intravascular ultrasound (IVUS) is a medical imaging modality that produces a sequence of cross-sectional frames of the vascular wall of arteries as a catheter is pulled-back inside blood vessels. It has become very useful for studying atherosclerotic diseases [1].

Various segmentation techniques have been developed for IVUS images of coronary arteries. Among methods that are based on statistics of the B-mode image, a Maximum A Posteriori (MAP) estimator was derived using Rayleigh statistics of the signal for the lumen contour segmentation [2]. A multi-surface 3D graph search using Rayleigh distributions and Chan-Vese terms is proposed in [3]. In [4], a knowledge-based approach is used to determine which level of gray corresponds statistically to the different regions of interest, i.e., the intima, plaque and lumen, in the context of the arterial wall segmentation. In [5], a non-parametric probabilistic model is integrated into a shape-driven method for the segmentation of the arterial wall. Among other probabilistic segmentation methods of the luminal borders, let us mention [6–8].

Several other techniques than the ones based on speckle statistics have also been proposed in the past five years. Edge information alone [9] or combined gray level intensity attributes [10,11] were used. Other segmentation algorithms are based on different textural features [12–15]. Gray level intensity and textural information were combined to detect the lumen boundary [6]; edge attributes were added for the external elastic membrane (EEM) [16]. In these methods, different frameworks were used to extract the vessel wall boundaries from the different image information, classifiers being the most prevalent recently [6,13,15,16]. Threshold and contour filtering [12] and binary morphological operations [14] were also proposed. Taki et al. [9] used deformable models while [10] combined them to graph search. Finally, a multi-agent segmentation [11] and a 3D parallel segmentation method [17] were investigated. Less recent techniques can be found in Section 4.

The aim of this work was to show that an adaptation of the fast-marching segmentation method developed in [18,19] for femoral artery IVUS segmentation is also powerful in the context of coronary imaging. Compared to femoral arteries [18,19], the artery wall of the coronaries presents a much more complex movement (see Fig. 1, left image). Moreover, since the IVUS images were acquired at a higher frequency (40 MHz) than in the case of femoral arteries (20 MHz), the lumen presents more speckle and hence, its appearance is more variable in the present study than in the context of [18,19] (see Fig. 1, right image). Therefore, we

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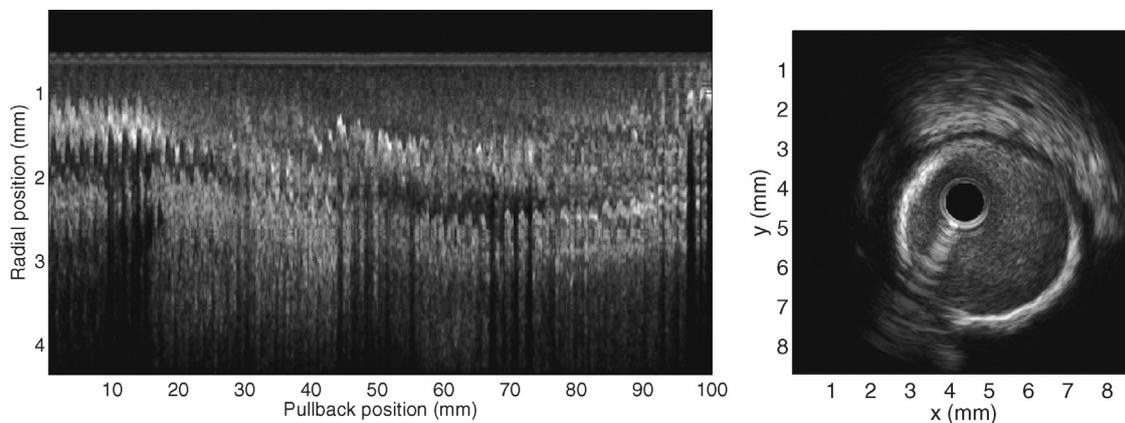


Fig. 1. Left: example of half a longitudinal cut of a pullback. Right: example of a cross-section that presents a calcified area from that in vivo sequence pullback.

considered an original modification of the speed function proposed in [18,19]. A textural gradient, defined in terms of the distribution of the gray levels in the different components of the vessel wall, was introduced in this new speed function. Moreover, mixtures of gamma probability density functions (PDFs) were used to model the gray level distribution of the log-compressed and filtered envelop of the IVUS images [20,21] that could not be modeled with Rayleigh distributions assuming uniform scattering tissues [22], as was used in our previous work. We also included a process that computes adaptive weights to calibrate the two components of the speed function to accommodate for various ranges of values coming from different image features. The vessel wall boundaries were modeled as layered contours that propagate simultaneously under that new speed function, which is based on a combination of complementary contour and region information. The multiple interfaces were propagated in the IVUS series of images after having been initially positioned using approximate manual segmentations on 2 perpendicular longitudinal views (L-views) of the 3D volume, to allow the tracking of the artery wall. This type of initialization is adapted for the segmentation of large pullbacks (several millimeters) where the vessel wall components might change across the sequence due to the heterogeneity of the image, and when adjacent cross-sections are discontinuous due to the beating heart movement for acquisitions that are not gated. This segmentation model handles contour irregularities, partial shadowing due to calcium inclusions within the plaque, side branches adjacent to the main artery to segment, the presence of a stent, injection of contrast agent or dissection as often observed for atherosclerotic coronary plaques.

2. Materials and methods

2.1. In vivo data

A total of 38 in vivo IVUS pullbacks from diseased coronary arteries was obtained from a database of Boston Scientific and clinical studies conducted at the Montreal Heart Institute. From these two sources, we segmented 20 sequences acquired with the Boston Scientific “Galaxy II” scanner, and 18 sequences with the “iLab” echograph. Ultrasound transducers at 40 MHz (mounted on catheters) were used in all cases. The IVUS cross-section image size varied between 8.2 mm and 11.4 mm. In what follows, a sequence refers to a series of IVUS images obtained by a pullback, at a constant speed, of the ultrasound catheter. The echograph “iLab” corresponds to the newest platform of Boston Scientific.

The segmentation algorithm was implemented on Matlab (version 7.04, the MathWorks, Natick, MA, USA), using some of our VC++ “mex” libraries. In order to comply with Matlab memory restriction, each of the 38 original sequences was broken up into 2

Table 1

The eight categories of comments written by the technicians for the 1388 frames from dataset 1 that were manually segmented.

Category	Comment	Number of frames
1	None	1179
2	Dissection	20
3	Calcium	91
4	Stent	72
5	Calcium and dissection	8
6	Branching	10
7	Branching and calcium	4
8	Injection of contrast agent	4

or 3 smaller sequences, each one of about 1000 frames, for a total of 78 sequences totalizing 82,848 frames.

A subset of images from each available pullback, with a step of twenty between frames, was manually segmented by experimented technicians of the Montreal IVUS Core Laboratory¹ at the Montreal Heart Institute. Overall, 4142 images were selected for the validation (82,848/20 images). Three technicians were involved in the manual segmentation of these images; the final contours were reviewed and approved by at least two technicians. The instructions given to the technicians were the following: if ever the visual perception of the image (and of the video sequence) did not allow the manual segmentation of either contour (lumen-intima or EEM-adventitia), then the image was classified as non-usable.² Consequently, some of the images could not be manually segmented and the total number of images that could be quantitatively analyzed (i.e., comparison of the algorithmic and manual segmentations) was 3207 (77.4% of the 4142 images, more precisely, 1388 of the 1782 “iLab” and 1819 of the 2360 “Galaxy II” frames). Thus, two datasets were used for the quantitative evaluation of the proposed segmentation method: dataset 1 consisting of the 1388 “iLab” frames (including 209 difficult frames that were nevertheless manually segmented – see Section 3.4) and dataset 2 consisting of the 1819 “Galaxy II” frames.

The technicians also wrote up in a lab book any difficulties encountered in the manual segmentation. The categories of their comments are summarized in Table 1

¹ The intraclass coefficients for interobserver variability associated with measurements of plaque and vessel volumes in this laboratory are 0.98 and 0.99, respectively [23].

² This instruction was imposed by the fact that a large portion of the database came from a clinical study where the area of the plaque was considered; the lumen-intima and EEM-adventitia contours are required to establish the atherosclerotic plaque area.

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