AN ACTIVE CONTOUR APPROACH TO AUTOMATIC DETECTION OF THE INTIMA-MEDIA THICKNESS

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ABSTRACT

In this paper, we propose a snake-based approach for the automatic detection of the intima-media thickness (IMT) of the far wall of the common carotid artery. The main problems to be faced are related, from one point, to the high level of speckle noise and, from the other, to the need of an accurate segmentation of the vessel structure for diagnostic purposes. In particular, the detection of the intima layer plays a fundamental role as it represents the initial contour from where the method should start. We propose an automatic segmentation approach which makes use of a first non linear filtering based on anisotropic diffusion followed by an iterative relaxation procedure. Once the intima layer has been detected our method tries to locate an optimal initial contour to detect the wall of the artery by minimizing of a modified energy functional.

Keywords: Segmentation, Active contour, Snake, Intima-media complex, Speckle, Anisotropic diffusion, Energy functional.

1. INTRODUCTION

Despite the wide use of advanced medical imaging techniques for improving the treatment and diagnosis of diseases, the automated yet accurate segmentation of anatomical structures continues to be a major obstacle for performing high throughput objective analysis. There have been proposed several methods to segmentation the anatomic structures in 2D e 3D representations [4, 3, 6]. The intima-media complex (Figure 1), (IMT) of the common carotid artery (CCA) can be used to predict cardiovascular events like myocardial infarction and stroke [8]. Today, the physicians are forced to make a manual segmentation of the intima-media complex to extract the interesting data: they select a point on the intima layer and one on the adventitia layer to obtain the thickness between these two points. This approach presents several problems: it's tedious to the physicians, it does not guarantee a reproducibility of the results and it doesn't allow to extract further interesting data like the area and standard deviation of the of the intima-media thickness. To avoid these problems here we propose an automatic method, which allows to extract the characteristics of this structure.

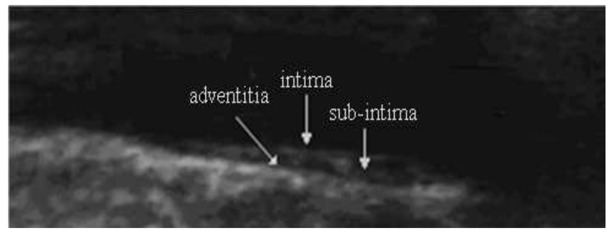

Fig. 1. Intima-media complex

Our method modifies the approach proposed by Cheng *et al*. [2] where the Cohen snake is modified and some constraints are imposed. The proposed approach has three distinction points. In a first time a pre-processing phase is applied to remove the noise from the image; with this filtering step we would emphasize the edges features and smooth the homogeneous regions to make the following phases easier. Then, the intima boundary is detected by an edge-sensitivity relaxation approach which makes this phase very fast and robust. In the last step, after an initial contour detection, the proposed method detects the adventitia layer by an energy minimization process where the classical snake energy functional definition is modified. In the sequel we describe the main steps of our approach and report a set of segmentation experiments over real images compared with those obtained by trained experts which routinely perform IMT detection in clinical purposes.

2. THE PROPOSED METHOD

Our method is composed of three main steps:

1. Initialization procedure;
2. Intima layer searching phase;
3. Adventitia layer searching phase;

All these steps are detailed below.

2.1. Initialization procedure

All active contour methods need to interact with the user. This interaction must identify the approximate shape or the initial position of the contour near the object of interest. To this purpose in the first step of our approach the user needs to select an interesting region nearby to the intima-media complex. The initializing procedure is very straightforward, in fact, our approach needs only two points: $P_1(x_1, y_1)$ and $P_2(x_2, y_2)$ which allow to compute the upper left and lower right vertexes of a rectangular region containing the intima and adventitia layers.

The selection of this region is basic to optimize the results of the method. Indeed, if in the superior part of the Region Of Interest (ROI) there are the wrongs boundaries, they can affect the model in the intima searching phase with their edge attraction. The wrong edge attraction is also important in the the computation of the adventitia layer. As explained below, we use an adapted snake model to select it. The main problem, however, is related to the selection of a good starting configuration which avoids the optimization process to be attracted by double contours of by the intima layer itself. The selection of a suited starting configuration is one of the main features of our approach and it is detailed in section 2.3.1

2.2. Intima layer searching phase

Indeed, for the IMT detection, ultrasound images are used and these images are well known to be often corrupted by speckle noise. This noise could be modeled as:

$$u_o = u + \sqrt{u}\, n$$

where u_o is the observed image, u is the original image and n is the Gaussian noise with zero main. Therefore, in this searching phase we must do a pre-processing step whose goal is to remove the speckle without destroying important image features. At this purpose we can use an anisotropic diffusion approach [1] where a non linear partial differential equation (PDE) is used to realize the intra-region smoothing and edge-preservation. This PDE performs well for images with additive noise but on speckled images it can even increase the speckle amount. To avoid this problem Yu and Acton [10] proposed the “Speckle Reducing Anisotropic Diffusion”(SRAD) where a new diffusion coefficient has been proposed to do an edge-sensitive speckle reduction.

Once we have a filtered image, the intima boundary can be detected. As can be seen from figure 1, it can be characterized as a continuous upper line with a relatively higher contrast with respect to the background. To select the points belonging to it, and in order to efficiently start the optimization process aimed at the detection of the adventitia layer, we approach the problem with a simple iterative procedure for constrained segmentation. In particular, it is enough to use an iterative scheme based on entropic thresholding together with with a continuity constraint for the intima line. Let T_g the threshold returned by the entropic thresholding on the filtered ROI. Then we move down each pixel of one position until it is becomes frozen. A pixel at position p can become frozen because at that point $|\nabla I(p)| \geq \mu T_g$, where μ is a constant, or because one of its neighbors has been set as frozen (continuity constraint). The procedure is as follows

1. Set as initial line the upper edge of the ROI.
2. Let $p1, ..., p_C$ the points of this line. At the beginning there are no frozen point.
3. choose an unfrozen point $p \equiv (x, y)$
4. If $|\nabla I(p)| \geq \mu T_g$ then freeze p, go to step 7
5. if one of the neighbours of p is frozen then fix p at the position with higher gradient between $(x, y-1)$, (x, y) and $(x, y-1)$, go to step 7
6. move p to $(x, y+1)$
7. if all the points have been fixed stop
8. go to step 3

The μ is a constant (after several observations we suggest 0.65 for its value), while the threshold T_g is a function of the image. T_g is calculated from the histogram gradient of ROI ($|\nabla I_{ROI}(x, y)|$) through the entropy threshold method.

The result of the algorithm is shown in Figure 2.

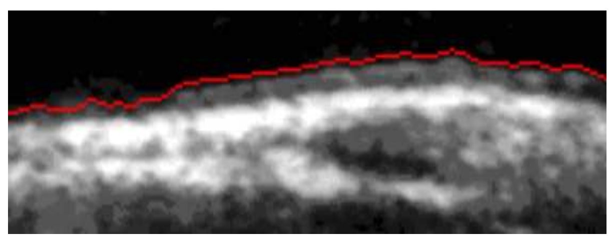

Fig. 2. Result of the intima layer searching phase

2.3. Adventitia layer searching phase

After selecting the intima layer, the model needs to move itself away from it. The aim of this displacement is to avoid that intima boundary influences the detection of the adventitia layer during the energy minimization process. Indeed, this structure could tend to attract the snake model in the wrong position. The selection of a good initial boundary for the adventitia snake is also important for performing the detection phase quickly. Therefore this searching phase is divided into two different parts:

- Initial contour selection;
- Energy minimization process;

2.3.1. Initial contour selection

Indeed, once that the intima layer has been correctly detected, it can affect the model with its edge attraction, also we must provide an initial contour to start the energy minimization process. Therefore, we must identify a first contour which represents a possible solution. In this paper we describe a new approach that reduces the wrong influence of the intima and ensures a fast convergence of the minimization process. The adopted idea is similar to ziplock snakes [7], but in our case some adaptation are imposed. Now we use the point $P_1(x_1, y_1)$, used for the initial ROI selection, (which must be located near and above to the adventitia layer) to create a contour. Before describing the algorithm we notice that an edge is characterized both by a big value of the $|\nabla I(x,y)|$ and $I_y(x,y)$ but this last value is negative. Therefore to identify an adventitia edge point we use the function $(|\nabla I(x,y)| + I_y(x,y))^2$. The limit is a chain of points $l_1, l_1, ..., l_C$ computed as follows:

- Step 1

  Set the point l_0 as: $l_1 = P_1(x_1, y_1)$

- Step 2

  For each point $l_2, l_2, ..., l_C$ search the location $l_i = l_{i-1}(x_{i-1}+1, y_{i-1}+j)$ with $j = -1, 0, 1$ where the function $(|\nabla I(l_i)| + I_y(l_i))^2$ have the higher value and $l_i(x_i, y_i)$ satisfies the condition: $l_i(x_i, y_i - s) = p_i(x_i, y_i)$ where $s \geq distance$.

$distance$ is a constant to ensure that the effect of the intima layer is null in the energy minimization process. This value can be considered as the intima thickness, in this way the multiple contour effects are avoided and the contour so defined is a solution which guarantees a fast convergence in the minimization process. Moreover, in this way the intima edge-attraction does not affect the energy minimization process.

2.3.2. Energy minimization process

A snake is a parametric contour defined into image plane $(x, y) \in \Re^2$ and it can be represented as $c(s)$ where s is the arc length [5]. The basic idea of the active contours is the association of an energy function which weights each possible configuration that the model can assume. This energy is the sum of three terms:

$$\varepsilon = \int (\alpha(s) E_{cont}) + \beta(s) E_{curv} + \gamma(s) E_{image}) ds \quad (1)$$

where the parameters α, β and γ control the influence of the relative terms in the energy expression. The first and second term represents the internal energy and the third the external energy of the model. Where the terms E_{cont} and E_{curv} of the internal energy promote respectively the continuity and smoothness of the contour.

$$E_{cont} = \left|\left|\frac{dc}{ds}\right|\right|^2, \qquad E_{curv} = \left|\left|\frac{d^2c}{ds^2} Bigg|\right|^2 \quad (2)$$

E_{image} is the term of external energy and it affects the model with the intrinsic properties of the image by the "*edge attraction*". Therefore the energy functional depends on the shape of contour and its location into image, and the final shape corresponds to the minimum of this energy. In the discrete domain a contour is a sequence of points $p_1, p_2, ..., p_C$, therefore the finite differences give:

$$E_{cont} = ||p_i - p_{i-1}||^2 \quad (3)$$

$$E_{curv} = ||p_{i-1} - 2p_i + p_{i+1}||^2 \quad (4)$$

And the energy functional becomes:

$$\varepsilon = \sum_{i=1}^{N} (\alpha E_{cont} + \beta E_{curv} + \gamma E_{image}) \quad (5)$$

For E_{image} we use a window with size $w \times w$, where the influence of more distant point decreases according to the distance from the center of the window. This term is calculated for the point *i* as:

$$E_{image} = \frac{\sum_W [v_p |\nabla I(i)| + v_p I_y(i)]}{\sum_W v_p} \quad (6)$$

where v_p is the corresponding value at the position in the window *W*. The contour computed in the previous step is a possible solution for our method.

The adventitia layer is the model obtained by a greedy minimization of the snake functional initialized as reported in section 2.3.1

3. RESULTS

In Figure 3 some results are reported. In these figures minimum and maximum thickness of the intima-media complex contents are reported. The complete results of an ultrasonographic image is shown in Figure 3, where have been extracted other interesting data: the area and the standard deviation. In order to have a quantitative evaluation of the results, we collected a set of test cases with a manual segmentation performed by expert physicians trained for performing IMT measurement in clinical practice. We report in table 1 the obtained results showing that the method tends to efficiently detect the IMT complex with an error which physician judge compatible with the application area.

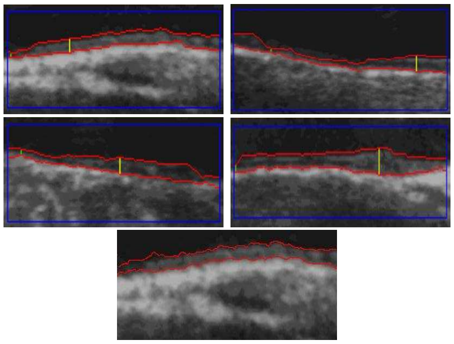

Fig. 3. Some results of *IMT Snake*

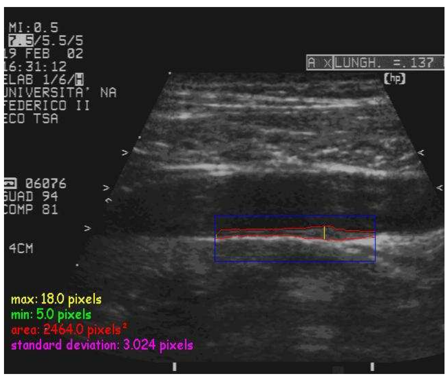

Fig. 4. A complete result of *IMT Snake*

Measuring	Percentage Corrects	Percentage False Positive	Percentage False Negative
Case 1	94.17%	0.52%	5.31%
Case 2	94.13%	2.07%	3.80%
Case 3	94.31%	3.66%	2.03%
Case 4	94.30%	1.45%	4.25%
Case 5	84.78%	5.24%	9.98%

Table 1: Quantitative results.

4. CONCLUSION

The paper reported a method to detect the intima-media thickness (IMT) with a new approach based on active contours. This approach allows to physicians to analyze the intima-media complex automatically, also it guarantees the reproducibility of the results and the extraction of the other interesting data, which can't be extracted with a manual segmentation. Our approach works well in noisy images also thanks to a filtering preprocessing step; further, if the point $P_1(x_1, y_1)$ is chosen correctly, it's robust in multiple contour presence, so in this case the knowledge of the user is a fundamental requisite. The reported algorithm has been implements as a plug-in of an open source image processing tool (ImageJ) and can be downloaded from `http://wwww.scoda.unisannio.it`.

5. REFERENCES

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