SEGMENTATION OF THE COMMON CAROTID ARTERY INTIMA MEDIA USING ACTIVE CONTOUR MODELS

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Abstract: Ultrasound measurements of the human carotid artery intima media thickness are conventionally obtained using manual tracing between tissue layers. This article consists of different approach, when intima media thickness is determined automatically. Tissue layers are detected by use of active contour segmentation. This method does not use any type of gradient, only intensity based image is needed. Therefore, robustness to speckle noise is present. A total of 15 carotid artery ultrasound images is analyzed to determine wall thickness. For evaluation, each of the images contains manually added marks by an expert.

Keywords: Ultrasound imaging, Active contour methods, Segmentation, Carotid artery, Intima media thickness

1 THEORETICAL BACKGROUND

1.1 Intima media thickness

Intima media thickness (IMT) of the common carotid artery can serve as a parameter of early indication of the development of some types of cardiovascular desease. According to the literature, IMT is directly associated with an increased risk of myocardial infarction and strokes, observed in elderly adults, without any previous history of cardiovascular diseases [3]. Moreover, IMT is correlated with atherosclerosis present in other body arteries. As the disease progresses, IMT initially increases along the artery and in later stages develops forms of discrete lesions or plaques. These continue to grow and obstruct blood flow. Physiological IMT value is about 0.75 mm. IMT greater than 1 mm is likely indicative of increased risk of cardiovascular disease [1].

Ultrasound imaging is a non-harmful method, which is capable of real time analysis. It is well established in the assessment of IMT. With image quality getting better in later acquisition systems, the problem of imaging artefacts or speckle noise remains present, causing IMT measurements difficult. Furthermore, in elderly patients, acoustic holes (echo-dropouts) in the adventitia layer are present as another source of difficulties [1], [3].

1.2 Active contour methods for segmentation

Active contour based segmentation is a set of methods using an initially defined curve, which is evolving in time. The curve may be defined as a set of points, spline interpolating function or parametrically defined curve. The last case may be, in some literature denoted as geometrical contour based segmentation.

The physical principle of these sets of methods is curve shape changing due to the forces acting on this curve, in time. Most commonly, there are two types of acting forces. Internal forces are derived from

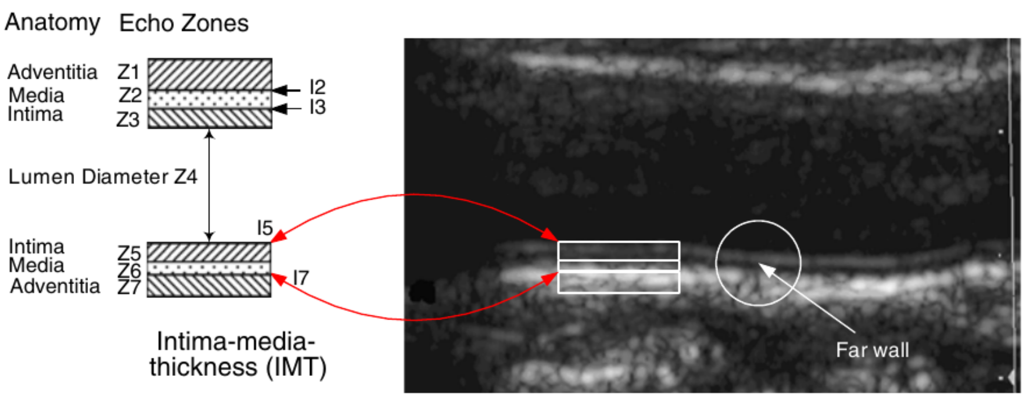

Figure 1: Common carotid artery anatomy echo zones. IMT is defined as distance between blood intima interface and the adventitia interface line. Right part of the image shows labelling real artery echo zones [1].

contour properties, such as tension or strain. On the other side, external forces are image dependent. Most often, gradient is used to calculate external force.

In this paper, active contour method without using gradient is used. Contour is defined in parametric space, in the form of a matrix of the same dimension as the original image with a scalar value assigned to each point. The zero level set then defines the curve. Points with a value greater than zero are representing area inside the segmented object, points with a value lower than zero, the area outside the object. Internal energy for each point of the parametric space is calculated using four-neighborhood of the point. An external force is then calculated using original intensity image. Finally, the image is divided into two distinct areas. Initial shape is always automatically placed circle in the middle of the image with a radius dependent on image size [2].

2 METHOD

2.1 PREPROCESSING

The only manual step is image cropping, because image borders contain useless information, as active contour methods uses all pixels to calculate external force. More concretely, mean intensity of an area outside object defined by the zero level set and inside an object is calculated at each step. Image cropping is the first step, implemented as the initial GUI window.

2.2 SEGMENTATION

At the input of the segmentation, the original image without any preprocessing a part of cropping is used. After this step, every part of the method is automatic with a possibility of modifying method parameters, which are set to their default value based on empirical testing.

The initial curve is defined as a parametric space $\phi_{i,j}$ with equation:

$$\phi^0_{i,j} = (-\sqrt{(i-y_s)^2 + (j-x_s)^2 + r})/k, \tag{1}$$

where i, j are coordinates in parametric space, which is defined as a matrix of image size. $[x_s, y_s]$ are coordinates of the middle of the circle, r is radius and k is used to lower values in parametric space resulting in better curve growing. The whole method is computed with following an equation:

$$\frac{\phi_{i,j}^{n+1}-\phi_{i,j}^{n}}{\Delta t} = H(\phi_{i,j}^{n})[\frac{\mu}{h^2}\Delta_{-}^{x}\cdot\left(\frac{\Delta_{+}^{x}\phi_{i,j}^{n+1}}{\sqrt{\Delta_{+}^{x}\phi_{i,j}^{n}/(h^2)+(\phi_{i,j+1}^{n}-\phi_{i,j-1}^{n})^2/(2h)^2}}\right)+$$
$$\frac{\mu}{h^2}\Delta_{-}^{y}\cdot\left(\frac{\Delta_{+}^{y}\phi_{i,j}^{n+1}}{\sqrt{\Delta_{+}^{y}\phi_{i,j}^{n}/(h^2)+(\phi_{i+1,j}^{n}-\phi_{i-1,j}^{n})^2/(2h)^2}}\right)- \tag{2}$$
$$\nu-\lambda_1(u_0(i,j)-c_1(\phi^n))^2+\lambda_2(u_0(i,j)-c_1(\phi^n))^2],$$

where μ, ν, λ_1, λ_2, h and Δt are method constants. $u_0(i,j)$ are pixels from the original intensity image, located at the coordinates i,j. In this equation, multiple variables need to be explained. $\Delta_{+}^{x}, \Delta_{+}^{y}, \Delta_{-}^{y}$ and Δ_{-}^{x} are difference equations calculated from neighbourhood points in parametric space with equations:

$$\Delta_{-}^{x}\phi_{i,j} = \phi_{i,j}-\phi_{i-1,j} \tag{3a}$$
$$\Delta_{+}^{x}\phi_{i,j} = \phi_{i+1,j}-\phi_{i,j} \tag{3b}$$
$$\Delta_{-}^{y}\phi_{i,j} = \phi_{i,j}-\phi_{i,j-1} \tag{3c}$$
$$\Delta_{+}^{y}\phi_{i,j} = \phi_{i,j+1}-\phi_{i,j} \tag{3d}$$

c_1, respectively c_2 represents the mean value inside and outside segmented object, where $\phi_{i,j} > 0$ inside the object and $\phi_{i,j} < 0$ outside the object. Their mathematical representation is:

$$c_1(\phi) = \frac{\sum_{\phi\geq 0} u_0(i,j)}{\sum_{\phi\geq 0} 1} \tag{4}$$

$$c_2(\phi) = \frac{\sum_{\phi< 0} u_0(i,j)}{\sum_{\phi< 0} 1} \tag{5}$$

Last variable is an alternatively expressed Heaviside function with the same behaviour in limits, but with continuous character in interval $[0,1]$. Its equation is:

$$H_k(x) = \frac{1}{2}(1+\frac{2}{\pi}\arctan(\frac{x}{k})) \tag{6}$$

Looking at the equation (2), it is obvious, that parametric value at the next step $\phi_{i,j}^{n+1}$ is located on both sides of the equation. Thus, this fact does not allow direct calculation of the new parametric value. Therefore, iterative calculation is used and $\phi_{i,j}^{n+1}$ is at the first step on the right side of the equation substituted by its best estimate, which is previous value of the n step, $\phi_{i,j}^{n}$. After k iterations, the result of the method is parametric space ϕ, where values greater than zero represent segmented objects and values lower than zero, background.

2.3 POSTPROCESSING

After finishing the iteration process, multiple steps are needed. First of all, a binary image is created from parametric space according to point belonging to inside of the object or to the background. This is distinguished by the sign of the concerned point value in parametric space.

Many small objects are present in the resultant binary image. To eliminate them, a morphological operation of closing is applied to get rid of them. This consists of dilatation followed by erosion. To achieve small objects suppressing, the erosion structural element is bigger concerning size than the dilatation one. Finally, the last step of postprocessing is contour detection. It consist of passing through every point in binary object marked as inside of the object and evaluating, whether the point is on the boundary or not. This evaluation is based on number of neighbours that are also marked as inner, e.g. point with 8 neighbours marked as inner is not placed on the boundary and point with 3 inner neighbours is evaluated as boundary point. Finally the example of an image with highlighted contour looks like the image below.

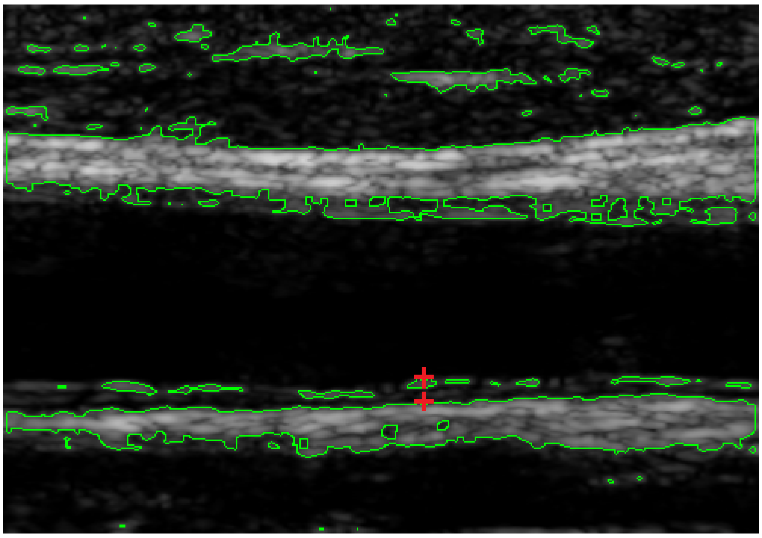

Figure 2: Example of an testing image of the carotid artery with highlighted contour.

2.4 IMT CALCULATION

The last step is to evaluate IMT, which is evaluated at the bottom part of the carotid artery. As it could be seen from the figure 2, the segmentation process ends with segmenting adventitia as the dominant object on the image. Some pixels above, small objects representing intima are segmented. Then, IMT is the distance between top of these objects and the first pixel of adventitia contour.

First of all, the original image is cropped the way, that only bottom part of the artery is available for the next step. Supposing that the lumen of the artery has minimal average intensity values, using average intensity projection along x axe, following by an averaging filter, the lumen can be identified easily. This is the origin, where image is cropped. The number of colons remains constant.

It is important to point out, that object boundary is one pixel thin. This property is used to calculate IMT as this distance in pixels is the difference between the first and third point of the contour along y axe. The algorithm systematically searches for the first, second and a third contour pixel column by column. The highest distance between first and third point is finally labelled as IMT. This computation method could fail when we realise that intima is not contoured along all the axe x. Looking for the distance difference, then would lead to meaningless results. But if we suppose that lumen does not contain any segmented objects, we could assume that the contour pixel with the highest position belongs to the intima. Then we could add a condition that while looking for the first pixel, his y coordinates cannot differ more than a few pixels from the mentioned contour pixel with the highest position.

3 EVALUATION OF ACHIEVED RESULTS

Implemented method has been tested on a set of 15 images with expert marks [1]. Resolution or in other words distance between two pixels was $d = 0.06$ mm. Distance between marks is computed, followed by multiplication by the distance between two pixels resulting in IMT value. IMT calculated by the algorithm is then compared to the expert values in a table below.

Table 1: Difference between expert marked values and algorithm computed values of IMT.

	IMT_{expert}		$IMT_{computed}$		ΔIMT
i	[pixel]	[mm]	[pixel]	[mm]	[mm]
1	18	1.08	20	1.20	-0.12
2	12	0.72	12	0.72	0
3	13	0.78	11	0.66	0.12
4	11	0.66	11	0.66	0
5	12	0.72	7	0.42	0.3
6	10	0.60	10	0.60	0
7	9	0.54	9	0.54	0
8	10	0.60	11	0.66	-0.06
9	10	0.6	14	0.84	-0.24
10	18	1.08	19	1.14	-0.06
11	13	0.78	7	0.42	0.36
12	11	0.66	9	0.54	0.12
13	16	0.96	14	0.84	0.12
14	10	0.6	9	0.54	0.06
15	9	0.54	9	0.54	0

We found that the average difference between computed and labelled values is $\Delta IMT = 0.04 \pm 0.15$ mm. This value shows, that method is sufficiently precise, because labelling by many experts could show similar differences and the uncertainty of the measured value lies in the range of physiological values. Moreover, it is sometimes difficult to distinguish intima or adventitia interface and active contour methods fails, because of the low contrast.

4 CONCLUSION

This paper deals with the active contour method for common carotid artery segmentation and following intima media thickness evaluation. An automatic method has been implemented, the only manual step remains image cropping. Achieved results show good precision comparing to expert generated results. Potential method failure is caused by low contrast images, where active contour segmentation does not recognise individual tissues. Another source of persisting problems is the eventual presence of objects in the lumen.

In the future work, it would be useful to fully automatize the method and to enhance image contrast by other preprocessing. To achieve better results, it is possible to detect adventitia interface, which has shape of a line, by the Hough transform and then to look at the distance from this interface to objects above.

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