International Journal of Pure and Applied Mathematics
Volume 113 No. 12 2017, 29 – 37
ISSN: 1311-8080 (printed version); ISSN: 1314-3395 (on-line version)
url: http://www.ijpam.eu
Special Issue

ijpam.eu

CAROTID ARTERY ATHEROSCLEROTIC PLAQUE DETECTION BY MINIMIZING ENERGY FUNCTION OF THE CONTOUR

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ABSTRACT: Segmentation of the lumen of atherosclerotic carotid arteries and studying the lumen geometry over time are difficult owing to irregular lumen shapes, noise, artifacts and echo lucent plaques. Active contour methods which are also called snakes by minimizing the energy function of the contour is proposed for fully automated ultrasound carotid artery plaque segmentation. Snakes are curves defined within an image domain that can move under the influence of internal forces coming from within the curve itself and external forces computed from the image data. It evolves a curve or a surface under constraints from image forces so that it is attracted to features of interest in an intensity image. It is performed for images with and without plaque and compared.

Keywords: Active contour, region based, chanvese active contour, iterations.

I. INTRODUCTION

Stroke is major health care problem and can be one of the main causes of long term disability and long even death worldwide. Several studies have demonstrated that patient with carotid atherosclerotic plaques carries an increased risk of cardiovascular events such as strokes, transient ischemic attacks, cardiac infraction, and even death. Ultrasounds have been widely used as a standard tool for inexpensive and non-invasive diagnosis of carotid atherosclerosis. To assess atherosclerosis (formation of plaques in arteries wall may cause narrowing of the lumen) different active contours techniques are used such as region based active contour, chanvese active contour and so on. So far carotid lumen segmentation has mostly been done on standard B-mode ultrasound (BMUS) images. However, carotid lumen segmentation in standard-BMUS images of subjects with atherosclerotic plaques is difficult and can be inaccurate due to irregular lumen shapes, noise in the lumen, artifacts and echolucent plaques.

1. Carotid artery

The carotid arteries are major blood vessels in the neck that supply blood to the brain, neck, and face. There are two carotid arteries, one on the right and one on the left fig 1. In the neck, each carotid artery branches into two divisions: The internal carotid artery supplies blood to the brain. The external carotid artery supplies blood to the face and neck. Like all arteries, the carotid arteries are made of three layers of tissue: Intima, the smooth innermost layer. Media, the muscular middle layer, Adventitia, the outer layer fig 2. The carotid sinus, or carotid bulb, is a widening of a carotid artery at its main branch point. The carotid sinus contains sensors that help regulate blood pressure. The carotid

artery pulse can normally be felt in the neck by pressing the fingertips against the side of the windpipe, or trachea.

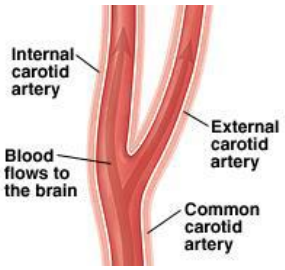


Fig. 1. Carotid Artery

2. Carotid Artery Condition

Carotid artery vacuities: Inflammation of the carotid artery, due to an autoimmune condition or an infection. Stroke: A sudden blood clot in the carotid artery can interrupt blood flow to the brain, causing a stroke. Fragments of cholesterol plaque in the carotid artery may also travel into the brain to cause a stroke. Carotid artery stenosis: Narrowing of the carotid artery, usually due to cholesterol plaque build-up, or atherosclerosis. Carotid artery stenosis does not usually cause symptoms until it becomes severe. Carotid artery aneurysm: A weak area of the carotid artery allows part of the artery to bulge out like a balloon with each heartbeat. Aneurysms pose a risk for breaking, which could result in a stroke or severe bleeding, or haemorrhage.

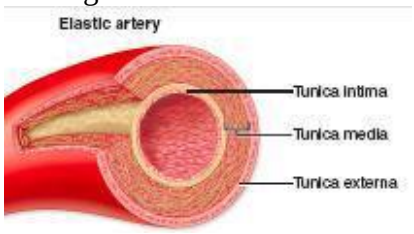


Fig. 2 Layers of Carotid Artery

3. Stages of Atherosclerosis

Fig 3 Although the exact biological process is not completely understood, scientists have described three different stages of atherosclerosis that lead to the "clogging" of your arteries.The fatty streak: The first evidence of atherosclerosis can be found in children 10 to 14 years of age. The "fatty streak" appears as a yellow streak running along the major arteries, such as the aorta. The streak consists of smooth muscle cells, which are filled with cholesterol, and macrophages (a type of immune system "scavenger" cell that removes harmful substances, such as excess cholesterol particles, from the bloodstream). The fatty streak alone does not cause any symptoms but, over time, can develop into a more advanced form of atherosclerosis called fibrous plaque. Fibrous plaque: A fibrous plaque forms in the inner layer of the artery. The plaque consists of large numbers of smooth muscle cells, macrophages, and lymphocytes (a type of white blood cell that typically responds to an infection or injury). These cells are all filled with cholesterol. As the fibrous plaque grows, it projects into the space inside the artery where the blood is flowing. Complicated lesion: The last stage of atherosclerosis occurs when the fibrous plaque breaks open, exposing the cholesterol and connective tissue underneath. This rupture provokes a strong clotting reaction from your blood, such as when you have a cut. The combination of fibrous plaque and the blood clot is called a complicated lesion.

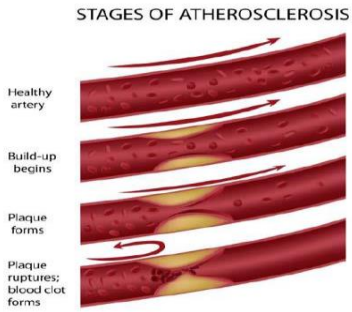


Fig. 3.Stages of Atherosclerosis

However carotid lumen segmentation is mostly done based on standard-BMUS images fig 4 and fig 5. Active contours or snakes are curves defined within an image domain that can move under the influence of internal forces coming from within the curve itself and external forces computed from the image data.

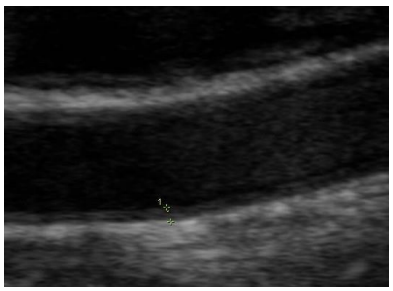


Fig.4. Ultrasound image of artery without plaque

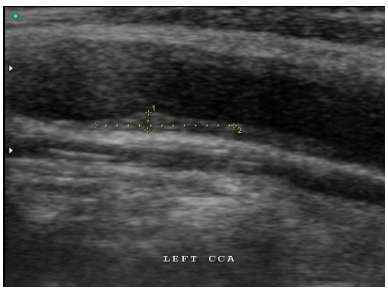


Fig.5. Ultrasound image of artery with plaque.

II. EXPLANATON

1. Active Contour

Active contours are widely used in image segmentation. An active contour is an energy minimizing that detects specified feature within an image its flexible surface can be dynamically adapted to acquire edges or object in an image.

2. Energy Formulation

Energy Formulation is a simple elastic snake defined by a set of n points vi

Where i = 0……(n-1)
The internal elastic energy term Eternal and the external edge-based energy term and External The purpose of the internal energy term is to control the deformations made to the snake, and the purpose of the external energy term is to control the fitting of the contour onto the image. The external energy is usually a combination of the forces due to the image itself and the constraint forces introduced by the user Image and the constraint forces introduced by the user Econ. The energy function of the snake is the sum of its external energy and internal energy [1].

$$E_{snake} = 0 \int 1E_{snake}(v(s))ds = 0 \int 1 (E_{internal}(v(s)) + E_{image}v(s)) + E_{conv}(s)))ds$$

The internal energy of the snake is composed of the continuity of the contour E_{cont} and the smoothness of the contour E_{curv}

$$E_{internal} = E_{cont} + E_{curv} \quad (2)$$

III METHODOLOGY

1. Region based active contour

The framework region-based active contours uses local statistics of object and background instead of global statistics. Each pixel on the curve is considered separately, and energy function is calculated in its own local region. The evolution curve will move to the minimum energy, which is namely the object boundary. The flow chart of the proposed model is shown in Fig [6]. In the first place, the initial contour surrounded the colon tissue has been created. Then the new energy functional based on local information is established. Finally, the surface of the level set method is rapidly evolved, thus the object boundary is obtained. In order to accelerate the algorithm execution, the value of signed distance function is only calculated on the narrow band around the initial contour [2][3].

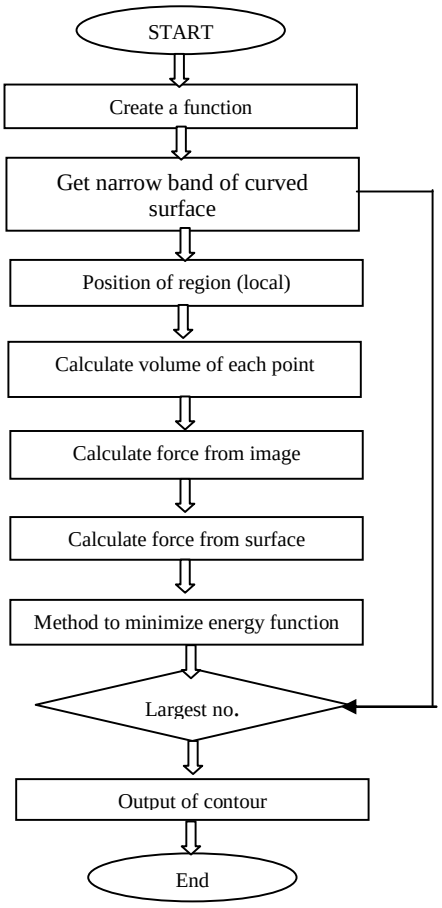


Fig. 6. Flow Chart

2. Constructing energy function

Deformable contour is a curve X(s) = (X(s), Y(s)), which moves though the spatial domain of an image to minimize the following energy functional:

$$\mathbf{E(x) = E_{internal}(X) + E_{external}(X)} \quad (3)$$

Internal energy of snake is the summation of elastic energy and bending energy and is given as:

$$\mathbf{E_{internal}} = \frac{\partial}{\partial s}\left(\alpha \frac{\partial X}{\partial s}\right) - \frac{\partial}{\partial s}\left(\frac{\partial}{\partial s}\right)\left(\beta\left(\frac{\partial}{\partial s}\left(\frac{\partial X}{\partial s}\right)\right)\right. \quad (4)$$

The first term discourages stretching and makes the model behave like an elastic string. The second term discourages bending and makes the model behave like a rigid rod. The external energy is given as the potential energy:

$$\mathbf{E_{external}} = -\nabla\left(P(X)\right) \quad (5)$$

To find the object boundary, parametric curves are initialized within the image domain and are forced to move toward the potential energy minima under the influence of both the forces. The level set method has the property of automatic topology adaptation. In the level set method, the curve is represented implicitly as a level set of a 2-D scalar function referred to as the level set function which is usually defined on the same domain as the image. The level set is defined as the set of points that have the same function value. Instead of tracking a curve through time, the level set method evolves a curve by updating the level set function at fixed coordinates through time. This perspective is similar to that of a Eulerian formulation of motion. An advantage of level set function is that it remains a valid function while the embedded curve can change its topology [4]. Given level set function $\varphi[x, y, t]$ with contour $X(s, t)$, as its zero level set, we have

$$\boldsymbol{\varphi}[\boldsymbol{X}(\boldsymbol{s},\boldsymbol{t}),\boldsymbol{t}\} = \mathbf{0} \quad (6)$$

Differentiating Eq. with respect to 't' and using the chain rule, we obtain

$$\frac{\partial \emptyset}{\partial t} + \nabla\emptyset \,.\frac{\partial \mathbf{X}}{\partial \mathbf{t}} = \mathbf{0} \quad (7)$$

where $\nabla\emptyset$ denotes the gradient of $\emptyset$

Assume that $\emptyset$ is negative inside the zero-level set and positive outside [5][6]. Accordingly, the inward unit normal to the level set curve is given by:

$$\mathbf{N} = -\frac{\nabla\emptyset}{|\nabla\emptyset|} \quad (8)$$

Using the curve evolution theory

$$\frac{\partial \emptyset}{\partial t} = V(k)(|\nabla\emptyset|) \quad (9)$$

Where k , the zero level set, is given by

$$\mathbf{K= \nabla \frac{\nabla \emptyset}{|\nabla \emptyset|}} \quad (10)$$

2. Chanvese active contour

Chan and Vese proposed an active contour model which can be seen as a special case of the Mumford–Shah problem. For a given image I in domain Ω, the CV model is formulated by minimizing the following energy functional:

$$\mathbf{E(C,c1,c2) =} \boldsymbol{\lambda 1} \int |\boldsymbol{I}(\boldsymbol{x},\boldsymbol{y}) - \boldsymbol{c1}|\boldsymbol{dxdy} \int |\boldsymbol{I}(\boldsymbol{x},\boldsymbol{y}) - \boldsymbol{c}.\boldsymbol{c}|\boldsymbol{dxdy} \quad \mathbf{(11)}$$

where c1 and c2 are two constants which are the average intensities inside and outside the contour, respectively [7][8][9]. With the level set method, we assume

$$\mathbf{C = \{(x,y) \in \Omega\ (x,y)=0\}} \quad (12)$$

$$\mathbf{Inside\ C = \{(x,y) \in \Omega\ (x,y)>0\}} \quad (13)$$

$$\mathbf{Outside\ C = \{(x,y) : (x,y)<0\}} \quad (14)$$

$$\mathbf{C1}(\emptyset) = \frac{\int \boldsymbol{I}(\boldsymbol{x},\boldsymbol{y}),\boldsymbol{H}(\emptyset)\boldsymbol{dxdy}}{\int \boldsymbol{H}(\emptyset)\boldsymbol{dxdy}} \quad (15)$$

$$\mathbf{C2}\emptyset) = \frac{\int \boldsymbol{I}(\boldsymbol{x},\boldsymbol{y}),(\mathbf{1}-\boldsymbol{H}(\emptyset))\boldsymbol{dxdy}}{\int(\mathbf{1}-\boldsymbol{H}(\emptyset))\boldsymbol{dxdy}} \quad (16)$$

By incorporating the length and area energy terms into Eq. (i) and minimizing them, we obtain the corresponding variational level set formulation as follows:

$$\frac{\boldsymbol{\partial \emptyset}}{\boldsymbol{\partial t}} = \boldsymbol{\delta}(\emptyset)[\boldsymbol{\mu div}\left(\frac{\nabla \emptyset}{|\nabla \emptyset|}\right) - \boldsymbol{v} - \boldsymbol{\lambda 1}(\boldsymbol{I}-\boldsymbol{c1})(\boldsymbol{I}-\boldsymbol{c1}) + \boldsymbol{\lambda 2}(\boldsymbol{I}-\boldsymbol{c})(\boldsymbol{I}-\boldsymbol{c})] \quad (17)$$

Where,$\mu \geq 0, v \geq 0, \lambda 1 > 0, \lambda 2 > 0$ are fixed parameter,
μ= controls the smoothness of zero level set,
n= increases the propagation speed,
λ1 and λ2= control the image data driven force inside and outside the contour
∇is the gradient operator
H(∅) is heavy side function
$\delta(\emptyset)$is dirac function

IV. RESULT

Following results were out for these two methods that is chanvese and region based active contour. Following number of iteration can be seen from the output of active contour methods.

1. Region based active contour output

(a) Initial seed (middle) (b) Initial seed (top left)

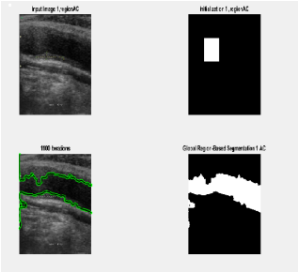


Fig 7. Initialize contour iterations, global region based segmentation

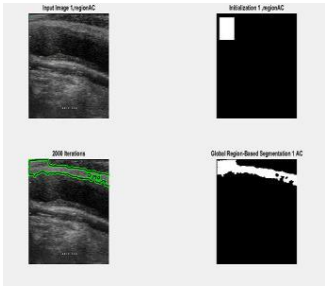


Fig.8. Initialize contour, iteration, global region based segmentation

(c) No seed

(d) Initial seed without plaque

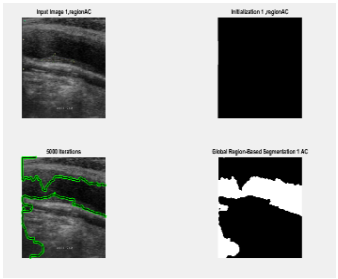


Fig. 9 Initialize contour, iteration, global region based segmentation

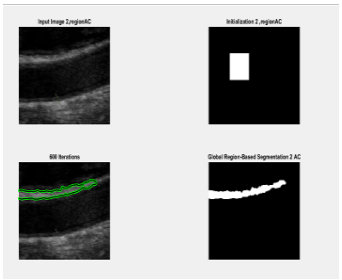


Fig. 10. Initialize contour, iteration, global region based segmentation

Initialize square seed	Total no of iteration
Upper left	2000
Bottom right	1580
middle	1100
No seed	4000

Table 1: Iteration based on seeds (with plaque)

Initialize square seed	Total no of iteration
Upper left	600

Table 2: Iteration based on seeds (without plaque)

By giving different mask value and no of iteration we get following output like mask m (334:435, 345:455);

2. Chanvese active contour output

Initial seed

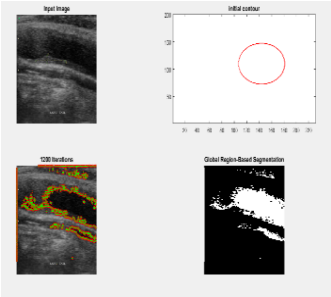


Fig.11. Initialize contour, iteration, global region based segmentation

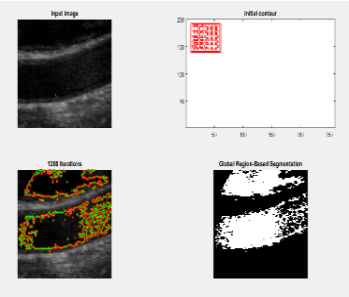


Fig. 12. Initialize contour, iteration, global region based segmentation

Initialize square seed	Total no of iteration
Upper left	1200
Upper left	1200

Table 3: Iteration based on Seed Chanvese

V. CONCLUSION

We have performed an accurate lumen segmentation of the carotid artery based on BMUS. Our segmentation approach enables the user to detect the lumen-intima border of the artery which can hardly be detected. Autonomous and self-adapting in their search for minimal energies. It is possible to track moving objects in temporal as well as spatial directions inevitably. The method is automated, an extensive evaluation was performed, and the results are accurate. Therefore, our method could become a valuable tool for the analysis of atherosclerotic carotid arteries. In the ultrasound image segmentation, there is much to upgrade and there are many methods to find but the round of possibilities of the new, fast and efficient methods up rise is getting smaller and so there come out the methods with the bigger computing difficulty again.

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