Anisotropic Diffusion Filter based Edge Enhancement for the Segmentation of Carotid Intima-Media Layer in Ultrasound Images Using Variational Level Set method without Re-initialisation

Sumathi. K, Anandh.K.R, Mahesh.V and Ramakrishnan.S

Abstract— **In this work an attempt has been made to enhance the edges and segment the boundary of intima-media layer of Common Carotid Artery (CCA) using anisotropic diffusion filter and level set method. Ultrasound B mode longitudinal images of normal and abnormal images of common carotid arteries are used in this study. The images are subjected to anisotropic diffusion filter to generate edge map. This edge map is used as a stopping boundary in variational level set method without re-initialisation to segment the intima-media layer. Geometric features are extracted from this layer and analyzed statistically. Results show that anisotropic diffusion filtering is able to extract the edges in both normal and abnormal images. The obtained edge maps are found to have high contrast and sharp edges. The edge based variational level set method is able to segment the intima-media layer precisely from common carotid artery. The extracted geometrical features such as major axis and extent are found to be statistically significant in differentiating normal and abnormal images. Thus this study seems to be clinically useful in diagnosis of cardiovascular disease.**

I. Introduction

According to the World Health Organisation reports by 2030, approximately 23.3 million people will get affected by Cardio Vascular Diseases (CVD's). Carotid atherosclerosis is the primary cause of CVD such as heart diseases and stroke that leads to death and adult disability [1]. Major cardiovascular events such as stroke are predicted with the measurement of Intima-Media Thickness (IMT) of common carotid artery. IMT increases with development of fatty plaque and cholesterol in the inner linings of the carotid arteries. Clinically, it is demonstrated that the increase in IMT is directly associated with risk of stroke [2]. The distance between lumen-intima and media-adventia interface is considered as biomarker for heart diseases. Since, the plaque formation starts in the walls of the arteries it causes luminal narrowing. The presence of plaques has also been correlated with degenerative pathologies such as vascular dementia and Alzheimer disease in addition to cardiovascular diseases [3]

B-mode Ultrasound (US) is a non-invasive imaging modality used to visualize the carotid walls quantitatively at lower cost. Compared to other imaging modalities namely magnetic resonance imaging, computed tomography and nuclear imaging, US imaging is widely preferred due to its accurate computation properties of the artery wall, the degree of stenosis and consistency of plaques [3].

US images are prone to speckle noise, hence denoising techniques which could preserve edges are essential. Some of the basic linear diffusion filters like median filter, Weiner filter and Gaussian filter reduce the speckle noise but produce blurred edges in the filtered image [4-6]. Anisotropic filtering is a non-linear technique which has been widely used for edge detection, image segmentation and restoration. This filter performs smoothing within region thereby avoiding smoothing across the boundaries and thus preserves sharp edges [7].

Computer aided diagnostic systems require segmentation and feature extraction techniques for the extraction and analysis of plaques. Segmentation techniques such as active contour methods are used to segment the boundary of intima media layer [8-15]. There are reports on the segmentation of carotid plaque using thresholding and region growing method. The segmentation of lumen and identification of far wall thickness have been carried out using Level Set [LS] method [16].

In conventional level set methods, practical challenges and mathematical errors occur due to re-initialisation. A variational level set which completely eliminates the costly re-initialisation procedure is introduced by Li et al. [17]. This method forces the level set function towards the boundary by maintaining signed distance property for geometric active contours. Level set methods have been adopted to segment the liver images [18, 19].

In this work, variational level set without re-initialisation is used to segment the boundary of intima-media layer in ultrasound B mode longitudinal images of carotid arteries. The anisotropic diffusion filter enhances the edges in the boundary of the intima-media layer and edge map extracted is used as a stopping boundary in the level set evolution. The geometric features such as major axis, extent, orientation, filled area, solidity and equivalent diameter are extracted from the segmented region and further analyzed.

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II. METHODOLOGY

A. Recording of ultrasound images

B-mode longitudinal ultrasound images of common tract of the Common Carotid Arteries (CCA) (normal=16 and abnormal=16) are considered in this study to segment the boundaries of distal (far wall) intima-media layer. The images were recorded from Global hospitals and health city, Chennai using Philips IU 22 Scanner using standard protocol. A linear array transducer of L9-3MHz range with high resolution and fundamental operating frequency of 6MHz is used for scanning. All the captured images of CCA revealed optimal visualisation of far wall and near wall.

B. Anisotropic diffusion filter

An anisotropic diffusion filter is given [13] by

$$I_t = div\left(c(x,y,t)\nabla I\right) = \frac{\partial}{\partial x}\left(c(x,y,t)I_x\right) + \frac{\partial}{\partial y}\left(c(x,y,t)I_y\right) \quad (1)$$

where, c is the conduction diffusion coefficient. The diffusion coefficient is considered locally as a function 'f' of magnitude of gradient of brightness to perform region specific smoothing operation which is given by

$$c(x,y,t) = f\left(\left\|\nabla I(x,y,t)\right\|\right) \quad (2)$$

The edges are preserved by proper choice of function 'f'. It also sharpens and brightens the edges. The function 'f' result in low coefficient value at inter-region edges by having large gradient strength and it should have high coefficient value in non-edge regions having low gradient strength. The possible function to preserves sharp edge is given by

$$f\left(\left\|\nabla I(x,y,t)\right\|\right) = \exp\left(\frac{\|\nabla\|}{K}\right)^2 \quad (3)$$

where K is the edge strength threshold.

C. Level set method without re-initialisation

The basic form of level set evolution equation can be written as

$$\frac{\partial \phi}{\partial t} + F\,|\nabla \phi| = 0 \quad (4)$$

where F is the speed parameter influencing the motion of the contour $\phi = \phi(x,y)$ is the Level Set Function (LSF). A variational level set formulation is given by

$$\varepsilon(\phi) = \mu\, p(\phi) + \varepsilon_m(\phi) \quad (5)$$

where penalty term $p(\phi)$ is added to maintain the signed distance function $|\nabla \phi| = 1$, $\mu > 0$ is a integer parameter, $\varepsilon_m(\phi)$ is external energy function that drives the motion of the zero level set curve ϕ [16]. The penalty term $p(\phi)$ can be written as

$$p(\phi) = \iint_\Omega \frac{1}{2}(|\nabla \phi| - 1)^2\, dxdy \quad (6)$$

by using variation of calculus and steady state solution is given by

$$\frac{\partial \phi}{\partial t} = -\frac{\partial \varepsilon}{\partial \phi} \quad (7)$$

In the variational level set formulation, external energy $\varepsilon_m(\phi)$ is used by the active contour models to move the zero level set curves towards the edges. An external energy for a function $\phi = \phi(t,x,y)$ is defined as

$$\varepsilon_{g,\lambda,v(\phi)} = \lambda L_g(\phi) + v A_g(\phi) \quad (8)$$

where λ>0 and v are constants, the terms $L_g(\phi)$ and $A_g(\phi)$ are defined as shown below

$$L_g(\phi) = \int_\Omega g\,\delta(\phi)\,|\nabla \phi|\, dxdy \quad (9)$$

$$A_g(\phi) = \int_\Omega g H(-\phi)\, dxdy \quad (10)$$

where δ is the univariate Dirac function and H is the Heaviside function. By incorporating the components of internal and external energy terms the level set evolution equation can be written [16] as

$$\frac{\partial \phi}{\partial t} = \tau\left\{\mu\left[\nabla^2\phi - div\left(\frac{\nabla \phi}{|\nabla \phi|}\right)\right] - vg\,\delta_\varepsilon(\phi)\right\} \quad (11)$$

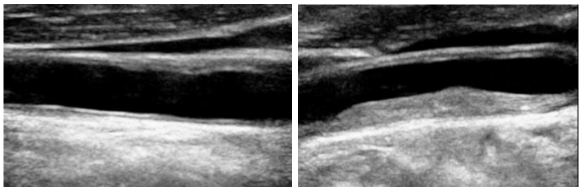
where g is the new edge indicator function obtained by taking the image gradient using anisotropic diffusion filtering.

Shape based geometric features are extracted from segmented intima-media layer and analysed. The number of pixels in segmented region denotes area. Major axis shows the object elongated between two points in region of interest. Major axis specifies the length of major axis in pixels of ellipse that has normalized second moment as the region. The minor axis is perpendicular to the major axis where the line has maximum length. Euler number with 8 connectivity concept gives the object number minus number of holes in the segmented region.

Equivalent diameter is scalar with same area as the region it specifies the diameter of a circle Solidity is given by the proportion of pixels in the intima-media regions and also present in the convex hull. Extent is the ratio of pixels in the region to the total bounding box. Minor axis is the length of the minor axis of the ellipse has normalized second moment as the region. Filled area is given by number of pixels in filled image.

III. RESULTS AND DISCUSSION

Fig. 1 a & b show the ultrasound images of common carotid artery for normal and abnormal subjects respectively



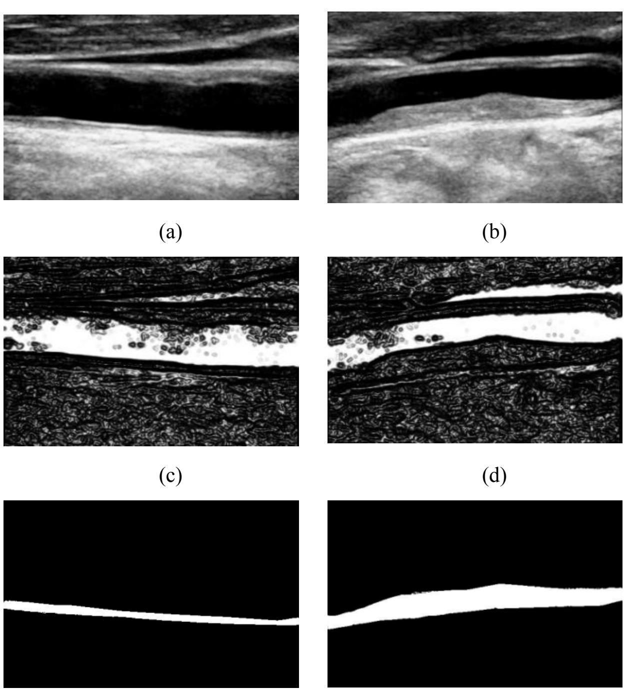
(a) normal (b) abnormal

Figure 1.Original grayscale ultrasound B-mode image showing near wall and far wall of the CCA boundary

It is observed that there exists an overlap in the intima-media layer of the far wall due to its variation in the contrast. The intensity variation is found to be homogenous throughout the intima-lumen and media-adventia interfaces. The boundary separation between the interfaces is not distinct and of low contrast.

In non-linear anisotropic diffusion filtering the numerical stability is maintained by appropriately choosing the integration constant. The whole diffusion process took 5 iterations to extract the edge map from all the images.

Fig 2 c & d show the results obtained by anisotropic diffusion filter. The continuous and high contrast edges are obtained with k=490 in both normal and abnormal images. The contour speed parameter α controls the motion of the level set function during evolution towards desired region of interest. A weak edge requires low α values and increased number of iterations. The zeroth level set is the contour provided manually. The edge map obtained from the optimal parameters values are used for the evolution towards desired boundaries in level set function. The parameters time step, μ, $\boldsymbol{\lambda}$, α and ϵ are chosen as 5, 0.04, 5.0.3, 1.5 respectively. It is observed that the diffusion results are obtained for iteration T=5 with well preserved edges.



(a) (b)

(c) (d)

(e) (f)

Figure 2. Ultrasound B-mode (a) normal , (b) abnormal, edge map for (c) normal, (d) abnormal, segmented mask for (e) normal and (f) abnormal images

When T is increased for large values inter-region edges are destroyed and fine details are lost due to over diffusion effect. The edge map is found to have continuous edges along the boundary of the intima-media layer in the carotid wall. The edge map for normal subject is observed to have thick edges separating the intima-media layer from the lumen. The edge map for abnormal subject shows clear deposition of plaque on the far wall.

The binary mask generated using evolved contour for normal and abnormal images are shown in Fig 2 e & f respectively. The boundaries of segmented intima-media layer in these images are found to be continuous and distinct. It is found that the adopted level set is able to extract the irregular boundary of intima media layer in abnormal images. An evident enlargement in intima-media layer is observed due to deposition of plaque on wall of common carotid artery.

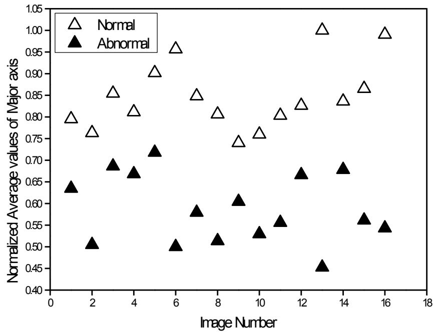
Table I shows the results for statistical analysis of geometric features extracted from the segmented region. It is observed that the feature namely major axis is found to be high in magnitude for normal images and standard deviation appears to be high in abnormal images.

TABLE I. STATISTICAL ANALYSIS OF GEOMETRIC FEATURES

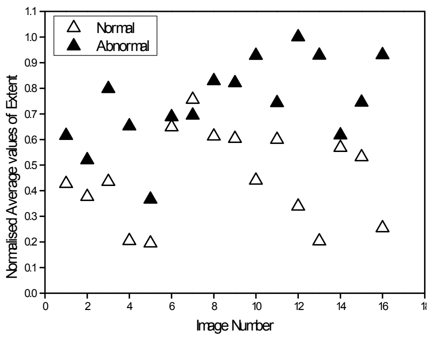
Features	Normal	Plaque disease
	Mean±Sd	***Mean±Sd***
Major axis*	0.8474±0.079	0.6636±0.14
Extent*	0.4748±0.22	0.7051±0.21
Orientation	0.7510±0.91	0.5900±0.27
Filled Area	0.7009±0.13	0.6170±0.18
Solidity	0.6325±0.131	0.7220±0.14
Equivalent diameter	0.8300±0.019	0.7700±0.11

*p < 0.0001 (Statistically significant), SD-Standard deviation

It is also found that the feature extent has higher magnitude due to enlargement of the intima-media layer in abnormal images. The mean and standard deviation values of features such as major axis and extent showed significant demarcation for normal and abnormal images with p<0.0001.The pathology of the carotid artery disease could be further demonstrated with the scattergrams plotted for significant features shown in Fig. 3 a & b. The normalized average values of the major axis are found to be high for normal subjects. The normalized average values of extent are high for abnormal subjects due to variation in deposition of plaque. These values are found to be distinct for abnormal subjects.



(a)



(b)

Figure 3. Scatter plot geometric features

IV. Conclusion

Ultrasound is a non invasive, non-ionising, painless and low cost imaging modality and is widely used for diagnosis of cardiovascular diseases. In this work an attempt has been made to segment the intima-media layer of CCA using variational level set method without re-initialisation. The anisotropic diffusion filter is used to extract edge map of this layer. This edge map is used for the evolution of level set function. Geometrical features are extracted from the segmented intima-media layers. Results show the anisotropic diffusion filtering could enhance edges of intima-media layer and sharpened edge map is able to drive the level set function towards true boundaries of intima-media layer. Geometric features of the segmented regions could differentiate normal and abnormal subjects. This analysis would be useful for automated diagnosis of cardiovascular diseases.

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