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Automatic Segmentation of Intima-Media Complex

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Abstract*—The intima media thickness (IMT) is considered as an important marker for the evaluation of the risk in the development of atherosclerosis. The evaluation of the IMT is carried out on B-mode ultrasound (US) images of the common carotid artery (CCA). The segmentation of the intima-media complex (IMC) is the key to evaluate the IMT. This project presents a fully automated segmentation algorithm, which is based on active contours and active contours without edges. The method incorporates anatomical information to achieve accurate segmentation. The level set formulation by Chan and Vese using random initialization segments the CCA US images into different distinct regions, one of which corresponds to the carotid wall region below the lumen and other to the far wall IMC[12]. The segmented regions are further processed by image normalization to remove image variability due to capture time, scanner and settings, which is followed by speckle removal. The lumen-intima boundary then provides an excellent initialization for the active contours using snakes that provide the final IMC segmentation. Using snake the IMC is segmented and mean absolute thickness is measured. It is found that CCA with normal condition has IMT in the range of 0.4mm to 1.5mm. The CCA having thickness beyond the specified range can be considered for thorough diagnosis.

***Keywords*— Active contours, common carotid artery, intima-media thickness, level sets, segmentation, ultrasound imaging**.

I. INTRODUCTION

Atherosclerosis is the degeneration of the arterial walls though lipid and other blood-borne material on vascular territories throughout the body. It is a condition where the arteries become narrowed and hardened due to an excessive build up of plaque around the artery wall. The disease disrupts the flow of blood around the body, posing serious cardiovascular complications. The carotid artery supplies the brain, and face. It is a common site for atherosclerosis, an inflammatory buildup of atheromatous plaque that can narrow the lumen of the common or internal carotid arteries.

Carotid artery has three layers namely intima, media and the adventitia. Carotid intima media thickness (IMT) is the distance between the lumen-intima and the media-adventitia interfaces. IMT is a measure of early atherosclerosis. IMT evaluation is quantitative, noninvasive and cost-effective. Using high-resolution B-mode ultrasound (US), it can be seen as the double line pattern on both walls of the longitudinal images of the common carotid artery (CCA). Intima media complex (IMC) corresponds to the intima and media layers of the arterial wall and segmentation of IMC is the measure of IMT.

The proposed method uses active contours. Active contours without edges with the incorporation of anatomical information are used to establish intensity information for the US images normalization. Following image normalization, active contours without edges are again used to identify an initial intima-media boundary. This boundary provides an excellent, completely automatic initialization for the snake segmentation algorithm that gives the final IMC segmentation.

The normalization is achieved automatically by the application of the Chan–Vese level sets that segments the lumen and the carotid wall. Additionally, the segmentation of the carotid wall provides an excellent lumen-intima initialization boundary for the final snake application. Following image normalization, active contours without edges are again used to identify an initial intima-media boundary. This boundary provides an excellent, completely automatic initialization for the snake segmentation algorithm that gives the final IMC segmentation. Active contours segment the IMC

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and provide IMT for evaluation. From a set of 20 images, it is found that arteries having IMT in the range of 0.4mm to 1.5mm are in normal condition. When IMT goes beyond the specified range it indicates the presence of atherosclerosis.

II. METHODOLOGY

In this project an automated algorithm is developed for IMC segmentation of the CCA. The presented method is completely automated and takes into account instrumental variability through image normalization. A Toshiba SSA-380-A ultrasound scanner with a high resolution and digital beam former with a linear 10-MHz transducer was used for the acquisition of the sonographic images. The CCA was examined by turning the neck of the study subject slightly to the left side. The transducer was positioned at the lateral side of the neck without any compression of the inner jugular vein, which was located between the transducer and the common carotid artery. The lumen was then maximized in the longitudinal plane with an optimal image of the near and the far vessel wall of the CCA. Thus, typical double lines were observed as the intima-media complex of the artery. The images were then saved on a Sony DKR 700 recorder.

*A)Ultrasound Images*For the evaluation of the IMT, B-mode longitudinal US images of the CCA are used, which display the vascular wall as a regular pattern that correlates with anatomical layers. The images cover longitudinally the carotid artery and show the near wall, the lumen and the far wall. IMT appears as a double-line pattern on both walls of the CCA in the image, and consists of the leading edges of two anatomical boundaries: the lumen-intima and media-adventitia.

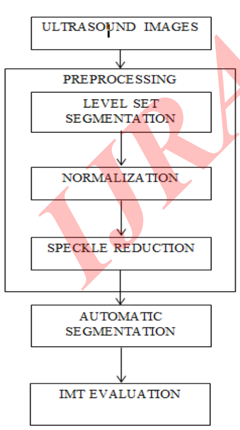

Fig.1 Block Diagram Representation

B) Level-Set Segmentation

Level set methods offer a highly robust and accurate method for tracking interfaces moving under complex motions: they work in a number of space dimensions but more importantly they can handle topological changes naturally. Using the level set formulation of the active contours without edges by Chan and Vese [1], [2], the regions corresponding to the lumen and the carotid wall (including the intima, the media and the adventitia) are automatically segmented.

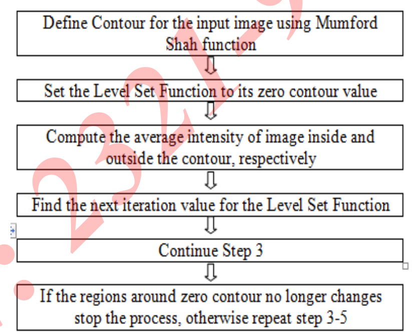

Fig.2 Flowchart for Level-set segmentation

C)Normalization

The normalization of B-mode US images for the CCA has been shown to address this variability using intensity adjustments that take into account anatomy and differences in tissue attenuation. The normalization reduces image variability due to capture time, settings, and scanners.

Algebraic (linear) scaling [1], [4] of the image was performed by linearly adjusting the image so that the median grey level value of the blood was 0–55, and the median grey level of the adventitia (artery wall) was 128–255. The scale of the grey level of the images ranged from 0 to 255. Thus the brightness of all pixels in the image was readjusted according to the linear scale defined by selecting the two reference regions.

ISSN: 2321-9653

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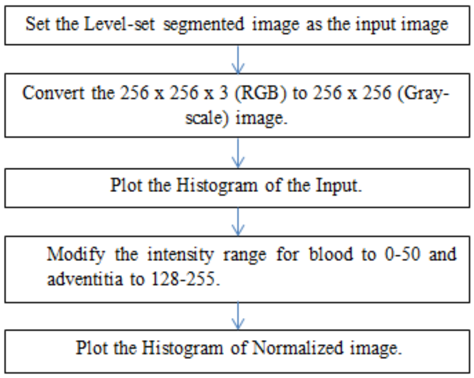

Fig.3Flowchart for Normalization

D) Speckle Reduction

Speckle noise is a granular noise that inherently exists in and degrades the quality of the active radar and synthetic aperture radar (SAR) images. Speckle noise in conventional radar results from random fluctuations in the return signal from an object that is no bigger than a single image-processing element. It increases the mean grey level of a local area.

Speckle noise has a significant impact on the correctness of boundary detection. The edges of the adventitia are also affected by this noise. Median filter is used to despeckle the image [3], [9], [10].

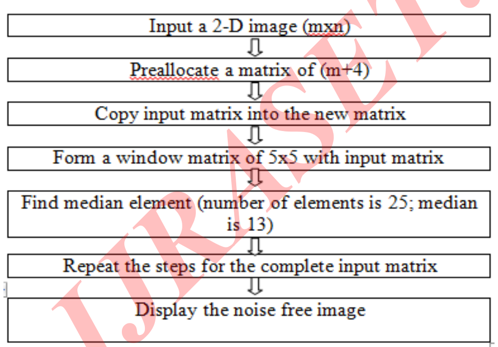

Fig.4Flowchart for Speckle Reduction

E) Automatic Segmentation

1) Snake: Active Contours- A snake is an energy minimizing spline guided by external constraint forces and influenced by image forces that pull it toward features such as lines and edges. Snakes are active contour models: they lock onto nearby edges, localizing them accurately. Scale-space continuation can be used to enlarge the capture region surrounding a feature. Snakes provide a unified account of a number of visual problems, including detection of edges, lines, and subjective contours; motion tracking; and stereo matching. We have used snakes successfully for interactive interpretation, in which user-imposed constraint forces guide the snake near features of interest[14]. The snakes segmentation technique implemented in this study is based on an energy function as defined by Williams and Shah [15], which is an extension of the initial snake functional defined by Kass et al. [10]. An additional image energy term, E_{image} (v) [16], which is given by the negative gradient of the current contour point gi,j as E_{image} (v) = -_gi,j^2, was added to our energy functional, as also proposed in [39]. For the calculation of the snake parameters, a(s), and b(s), we took into consideration the irregular spacing between the contour points of the snake and were calculated as proposed in [10].

The boundary of the far wall adventitia, resulting from the application of the Chan–Vese level set [12] provides an excellent initialization for the segmentation of the IMC using snakes [10], as in [6]. The extracted boundary, between the lumen and the adventitia approximates very closely the lumen-intima boundary and provides the contour points needed to run the snake. The gradient of the line that best fits the initialization boundary, using least squares error approximation, provides a constraint for the choice of points used to initialize the parametric active contour.

The segmentation of the IMC is achieved as in [6], minimizing the active contour energy functional [10] using the fast algorithm extension by Williams and Shah [15]:

$$E^{*}_{snake} = \int_0^1 E_{snake}(v(s))ds$$

$$= \int_0^1 (E_{internal}(v(s)) + E_{image}(v(s)) + E_{constraints}(v(s)))ds$$

where$\mathbf{v}(s) = (x(s), y(s))$ is the vector representation of the contour with the arc length s as the parameter. $E_{internal}$ corresponds to the internal regularization energy that imposes continuity and bending constraints and comprises two

INTERNATIONAL JOURNAL FOR RESEARCH IN APPLIED SCIENCE AND ENGINEERING TECHNOLOGY (IJRASET)

components, while E_{image} represents the image energy incorporating local gradient magnitude:

$$E = \int \{\tfrac{1}{2}\alpha(s)|v'(s)|^2 + \tfrac{1}{2}\beta(s)|v''(s)|^2 + \gamma(s)\,(-|\nabla I(v)|^2)\}ds$$

2) IMT Evaluation- Segmentation of IMC provides the important aspects to evaluate the intima media thickness. The segmentation of the far wall IMC can be evaluated using mean absolute distance.

Mean absolute distance $D_{|mean|}$is the mean value of the absolute Euclidean distance differences between the maximum thickness and the minimum thickness. It is defined as follows:

$$D_{|mean|} = I_{max} - I_{min}$$

$D_{|mean|}$provides a good approximation of theerror especially when the anatomy of the IMC segmented regionis mostly straight and horizontal but also tends to overestimatethe error otherwise.

III. RESULTS

Longitudinal B-mode ultrasound images of Common Carotid Artery are collected from different patients with normal cardiac conditions as well as from those with symptoms of atherosclerosis.

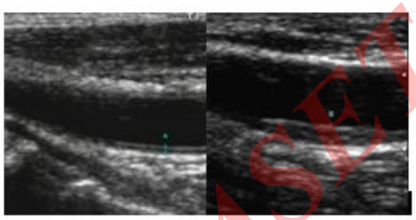

Fig.5Input CCA image of normal patient, Input image of patient with abnormality in the CCA.

The Chan–Vese level set segmentation is used to get a good initial segmentation of the carotid artery wall and to provide a good initialization for the parametric active contours method.

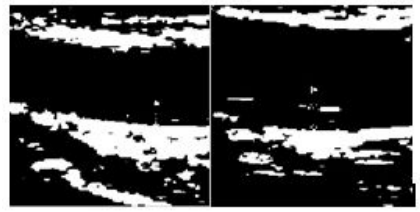

Fig.6 Level set segmented normal image, Level set segme-nted abnormal image

The normalization performs linear grayscale remapping so that median intensity value of the artery lumen has intensities between 0 and 50, and the median intensity value of the adventitia between 128 and 255 for the collected images.

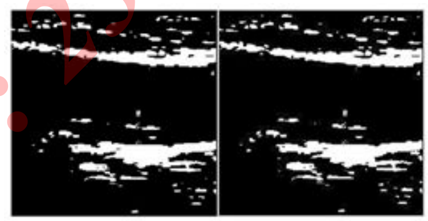

Fig.7 Grayscaleof Level-set segmented image of nomal patient, Normalized image of normal patient

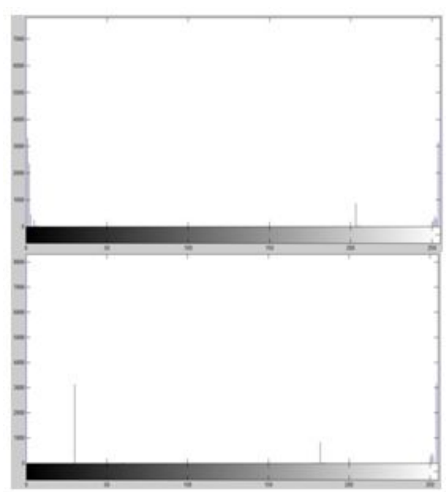

Fig.8. Histogram of Level-set segmented image of nomal patient, Histogram of normalized image of normal patient.

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Fig.9. Grayscale of Level-set segmented image of patient with abnormality, Normalized image of patient with abnormality.

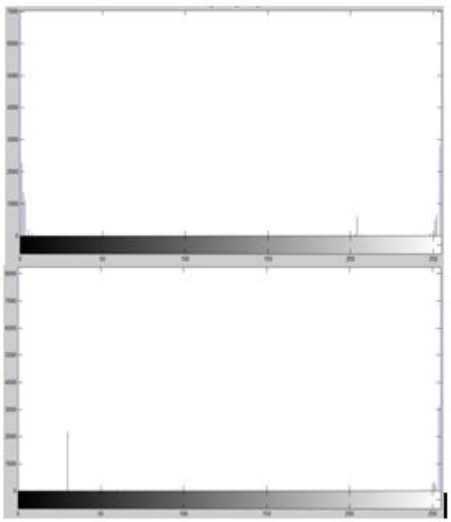

Fig.10. Histogram of Level-set segmented image of patient with abnormality, Histogram of normalized image of patie-nt with abnormality.

Speckle reduction is performed to remove the background noise and preserve the edges. The best result is achieved using Median filter. It smoothens the image without losing any important data.

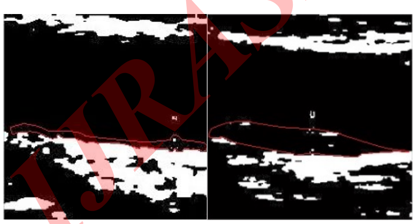

Fig.11. Snake Implementation on normal IMC, snake Implementation on abnormal IMC

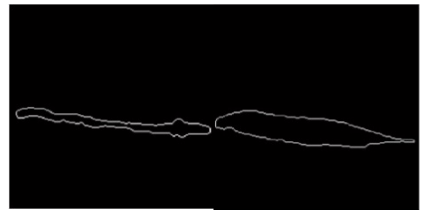

Fig.12.IMT Segmentation of normal CCA,IMT Segmentation of abnormal CCA

The active contour initialization using snake uses the contour points to select the region of interest and segments the IMC for further evaluation. The snake fits like an elastic band on the region of interest.

TABLE I

IMT Evaluation of normal CCA

US image	Maximum thickness(mm)	Minimum Thickness(mm)	Mean absolute thickness(mm)
Image 1	1.7853	0.7179	1.0673
Image 2	1.6648	1.1191	0.5457
Image 3	2.0998	1.6795	0.4204
Image 4	1.8323	0.7055	1.1267
Image 5	1.9293	1.4323	0.4970

TABLE II

IMT Evaluation of abnormal CCA

US image	Maximum thickness(mm)	Minimum thickness(mm)	Mean absolute thickness(mm)
Image 1	4.3288	1.6795	2.6493
Image 2	2.8482	0.8103	2.0379
Image 3	3.4572	1.6538	1.8034
Image 4	4.3288	1.3700	2.9588
Image 5	4.3322	2.2957	2.0365

The initma-media thickness is evaluated on a set of five normal and abnormal images each of segmented B-mode ultrasound longitudinal images of the common carotid artery. The maximum, minimum and absolute thickness is calculated for each image.

TABLE III

Comparision between IMT of normal and abnormal CCA

CCA	Maximum thickness(mm)	Minimum thickness(mm)	Mean absolute thickness(mm)
Normal	1.8623	0.8437	0.73142
Abnormal	3.8590	1.5619	2.2972

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INTERNATIONAL JOURNAL FOR RESEARCH IN APPLIED SCIENCE AND ENGINEERING TECHNOLOGY (IJRASET)

Comparing the mean thickness of the normal and abnormal arteries, it is found that the mean thickness for a normal IMC is in the range 0.4mm to 1.5 mm. When the IMT increases beyond this range, it can be considered as an abnormal diagnostic condition. The abnormal IMT can be considered to be detection of atherosclerosis and necessary remedial measures can be taken.

IV. CONCLUSION

The proposed method extracts the intima- media complex from the ultrasound images of common carotid artery. Level-set method segments the input images into the lumen and the carotid wall. The segmentation results combined with anatomical information forms the basis for the IMC segmentation. The image variability is reduced by normalization and speckle removal reduces the noise in the input images.

The active contour using snake segments the intima media complex which is used to evaluate the intima media thickness. Mean absolute distance is calculated for the segmented images and it is found that the carotid arteries in normal cardiac conditions have IMT in the range of 0.4mm to 1.5 mm. The arteries with IMT greater than the specified range have signs of atherosclerosis.

The presented technique represents a generalized and standard methodology towards completely automated and accurate IMT measurement. It may be used for aiding the clinicians through providing support in their examination, reducing not only evaluation time, but also the variability between readers whilst improving reproducibility.

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