

Common Carotid Artery Intima Media Thickness Segmentation Survey

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Abstract—The ultrasound imaging is very popular to diagnosis the disease because of its non-invasive nature. The ultrasound imaging slowly produces low quality images due to the presence of spackle noise and wave interferences. There are several algorithms to be proposed for the segmentation of ultrasound carotid artery images but it requires a certain limit of user interaction. The pixel in an image is highly correlated so the spatial information of surrounding pixels may be considered in the process of image segmentation which improves the results further. When data is highly correlated, one pixel may belong to more than one cluster with different degree of membership. There is an important step to computerize the evaluation of arterial disease severity using segmentation of carotid artery lumen in 2D and 3D ultrasonography and in finding vulnerable atherosclerotic plaques susceptible to rupture which can cause stroke.

Keywords—IMT measurement, Image Segmentation, common carotid artery, internal and external carotid arteries, ultrasound imaging.

I. INTRODUCTION

THE common carotid artery (CCA) is the one supplying the human head, specifically the front part of the brain, and neck, with oxygenated blood. Like other arteries, which purpose relies in the supply of blood from the heart, as the coronary arteries, the carotid is also in risk of developing several diseases, like atherosclerosis, known as the “hardening of the artery”, after the accumulation of fatty substances, i.e. lipoproteins, in the artery walls. This accumulation is known as “plaque” and decreases the blood supply. The carotid artery, specifically at the bifurcation, which separates the external (ECA) and internal (ICA) carotid arteries, is one very susceptible to atherosclerosis, mainly because of the high hemodynamic forces that can be found at the bifurcation and branching structures.

To diagnosis the cardiovascular diseases the non-invasive ultrasound imaging has been widely used. In particular it concerning the atherosclerosis with the evaluation of the intima-media thickness (IMT) assesses the distance between the lumen of the carotid artery. This measure, and consequent diagnosis of atherosclerosis among other cardiovascular diseases, is performed with the aid of B-mode ultrasound imaging, requiring the detection of not only the lumen

boundaries but as well as of both the near and far adventitia. Hence, it turned to be a great interest in the efficient automatic segmentation of the adventitia and lumen boundaries in B-mode ultrasound images of the carotid artery.

The widely used techniques like ultrasound B-mode imaging is used in image-based cardiovascular diagnosis due to the fact of the carotid being a superficial artery and quite suitable for this type of imaging. The B-mode images have difficulties, specifically in the segmentation of the structures involved, due to several imaging characteristics like low contrast, speckle noise, echo shadows and artifacts, which lead to images of very poor quality, that usually require the interaction of an expert. The literature review of some works uses several statistical distributions to cope the granular speckle noise in non-compressed ultrasound signals, and K-distribution. Actually most of the signals are actually used in ultrasound imaging and medical practice are log-compressed signals, which are therefore, unsuitable for the application of statistical distributions because of the reduced intensity range that is characteristic of this type of signal. The success of texture segmentation technique results in the classification of breast masses and liver and kidney tissues in ultrasound images. However, the segmentation of the carotid artery tends to be more difficult due to the extremely low degree of discrimination of this structure in the usual ultrasound B-mode images.

The segmentation procedure consists of two steps they are as follows: (i) the definition or estimation of a region of interest (ROI) of the carotid artery in the B-mode ultrasound image and (ii) the delineation of the wall boundaries, depending on the ROI definition, as the wall (being lumen, or intima, or adventitia) which is to target. For this reason, just have to consider that these two steps are not independent from each other, since the correct delineation of the artery wall in the segmentation algorithm is strictly connected to the correct definition of the ROI.

In this paper, a method is proposed for the automatic identification of the lumen region and consequent segmentation of the lumen boundaries in longitudinal B-mode images of the CCA. The method searches for hypoechogenic structures in the input image, and the lumen region of the CCA is identified based on mean and standard deviation calculations concerning the image intensity.

II. METHODS

There are numerous have been proposed for the segmentation of the IMC but, among these most of them are semiautomatic and needs user intervention. Hence, there are

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different methods have been developed for carotid artery segmentation. The techniques such as gradient- and edge-based techniques, dynamic programming techniques, texture and other image features, parametric active contours-based segmentations, region based image segmentation, edge based image segmentation, fuzzy theory based image segmentation, and threshold based image segmentation as well as combinations thereof. A review of some of the state of the art algorithms for IMT evaluation is presented in.

A. Parametric Active Contours Based Segmentation

D. Cheng et al. [1] proposed a snake's segmentation technique for detecting the intima-media layer of the far wall of the common carotid artery (CCA) in longitudinal ultrasound images, by applying snakes, after normalization, speckle reduction, and normalization and speckle reduction.

The computer assisted border tracing segmentation procedures have problems that are associated with it. They are as follows: (1) They do not take into consideration the speckle noise or the image normalization in the ultrasound image. (2) They are sensitive to the initial snake contour, or initial seed points, which need to be placed manually. If the initial contour is placed far away from the boundary of interest then the snake will not be attracted. (3) Some weighting factors that should be tuned due to the varied characteristics of the ultrasound instrumentation must be entered manually or empirically. Some other weights may be adjusted by a training procedure, which might be long and requires experts tracing. (4) The snake is implemented as a close contour that might not be that suitable for the IMC segmentation. (5) They require manual correction after automatic tracing. (6) In a number of cases there were no ground truth segmentation delineations from experts to compare to the computer assisted methods. (7) Different measurement procedures were used between the manual and the snake's segmentation methodologies. (8) Different criteria were used for assessing the performance of the segmentation algorithms. (9) They were evaluated on a limited number of images, where the intra- and inter-observer variability could not be assessed. The snake's segmentation method also utilizes image normalization and speckle reduction in ultrasound images of the carotid artery trying to overcome some of the above difficulties.

The image normalization carries brightness adjustments of ultrasound images. It improves image compatibility by reducing the variability. It is introduced by different gain settings, different operators, and different equipment and facilitates ultrasound tissue comparability. The leading edge of the adventitia Z7 (I7, and the Media layer Z6) can be affected due to presence of speckle noise and the attenuation of the probing sound wave by sound absorbing tissues. The texture of an image is not homogeneous, the intensity values can be varied from one to another and the boundary is incomplete. Hence it is important to despeckle the area of interest prior to segmentation. To delineate the wall and lumen boundaries, the B-mode image was used. In order to eliminate errors due to color artefacts and verberations occurring from the blood flow image. IMT initialization plays an important role to place the

initial snake contour as close as possible to the area of interest otherwise the snake may be trapped in local minima or false edges, and converge to a wrong location. Therefore the snake's segmentation technique has been implemented based on energy, which is an extension of the initial snake functional.

B. Dynamic Programming

Q. Liang et al. [2] proposed a Vessel wall positions are first estimated in a coarse-scale image, then detection of the boundaries is estimated in a fine-scale image here both image estimation is done by using multiscale dynamic programming which finds global optimum for a cost function. Cost function is a weighted sum of terms, in fuzzy expression form as it represents image features and geometrical characteristics of vessel interfaces.

The automated method is based on multiscale dynamic programming (DP) and includes optional modification by a human operator. Weighted terms in global evaluation function include local measure of echo intensity and the intensity gradient of image, and the boundary geometrical constraint. The optimal solution of the cost function is desired boundary. The intervention of human is also incorporated in DP. Multiscale DP method requires few human modifications and normally no operator guidance.

In human boundary determination, the global view prevails over the local view. DP is a unique tool for efficient search for global optimum. The cost function in automated procedure also includes factors as echo intensity and multiple image features, boundary formation as cost terms. In the human vision system, lower frequency components "where" information, driven the attention window to "what" information is mostly contained in higher frequency components. The latter concerns the detail of the object and is mostly contained in the higher frequency components.

Human perception processes often involve imprecise descriptions of the input information. If we let our automated procedure represent image features in fuzzy expressions, by adjusting the fuzzy membership function we may have more alternatives in imitating the human interpretation of the images. A prior knowledge plays an important role in the observer's perceiving and decision making process. In the automated system, such knowledge can be included in the design of the cost function terms. Moreover, it is believed that the expert data, that is, the manual tracing of the boundary by an expert, contain vast human knowledge. They can be used to train the system. The boundary search is based on a broad and global view of the image. If the automated detection system needs human assistance in ambiguous cases, this assistance should also be given within the framework of global optimality. Therefore, the human intervention is formulated and included in the cost function.

C. Texture Analysis

A. Mojsilovic et al. [3] proposed the local carotid arterial statin effects in 3D US image can be evaluated by using multi classifier image texture analysis tools. Thus the texture

analysis tools were used to evaluate the effect of 80 mg atorvastatin administered daily to patients with carotid stenosis compared to those treated with placebo. The 270 texture features can be extracted from seven texture techniques by using three dimensional carotid ultrasound images. These can be manually segmented carotid arteries based on the intima-media boundary [vessel wall (VW)]. Each and every individual texture features can be compared to the previously determined changes in [VW volume (VWV)] using the distance between classes, the Wilcoxon rank sum test, and accuracy of the classifiers. The result of texture features in maximal classification accuracy from each texture technique were selected using Pudil's sequential floating forward selection (SFFS) as a method of ranking each technique. Finally, SFFS-selected texture features from all texture techniques were used in combination with 24 classifier fusion techniques to improve classification accuracy.

Using the measurement of change in vessel wall volume (VWV), the distance between classes (DBC) Wilcoxon rank sum (WRS) p-value, and median accuracy measures (ACC) were 0.3798, 0.076, and 54.50%, respectively. Texture features improved the detection of statin-related changes using DBC to 0.5199, using WRS to 0.002, and ACC to 63.87%, respectively. The texture techniques that most differentiated between atorvastatin and placebo classes were Fourier power spectrum and Laws texture energy measures. The average classification accuracy between atorvastatin and placebo classes was improved from 57.22 (+ OR -) 12.11% using VWV to 97.87 (+ OR -) 3.93% using specific texture features. Furthermore, the use of specific texture features resulted in the average area under the receiver-operator characteristic curve (AUC) a value of 0.9988(+ OR -) 0.0069 compared to 0.617(+ OR -) 0.15 using carotid VWV.

Based on DBC, WRS, ACC, and AUC texture features derived from 3D carotid ultrasound were observed to be more sensitive in detecting statin-related changes in carotid atherosclerosis than VWV suggesting that texture classifiers can be used to detect changes in carotid atherosclerosis after therapy.

D. Edge Detection and Gradient-Based Techniques

B. Sumengen and B. Manjunath [4] proposed the variation of gray level is detects by the edge detection method, but it is sensitive to noise and may suffer from the focusing artifact. The image gradient was used in the edge detection method. For each column of the image the gradient of the intensity profile has been computed. It assumes that the pixels were belongs to the lumen were black and that the carotid wall layers originate with gradient transitions. It is a semiautomatic method; ROI is selected by the user. The pattern recognition, edge detection (PRED) algorithm, and the measurement algorithm were used for carotid IMT measurement. Its main task is to find out all the pixels belonging to the two required interfaces (LI and MA) for each wall. The measured intensity gradient was different from the theoretical one, due to noise. In order to reduce the effect of noise, a statistical thresholding was adopted before computing the image gradient. Robustness

of the edge detection algorithm had been evaluated with respect to the ROI. The gradient-based segmentation mainly suffers from the problem of superimposed noise, which precludes a proper individuation of the LI and MA transitions. The gradient performance was improved by the use of a first-order absolute moment edge operator (FOAM) and a pattern recognition approach. The overall performance of this methodology was very high: IMT measurement error was equal to $10.0 \pm 38.0 \mu\text{m}$. Moreover, FOAM operator and intelligent procedure determines maxima, ensuring a good robustness to noise. As the technique is real-time, it suits well to clinical application. It is a semiautomatic technique. Recently, the new method was introduced in which it employs a multistep gradient-based algorithm. This method principally uses intensity, intensity gradient, and interface continuity of pixels to determine the ultrasound interface.

E. Threshold Based Image Segmentation

S. S. Al-amri and N. V. Kalyankar [5] proposed the histogram thresholding is used to segment the given image; particular pre-processing and post-processing techniques required for threshold segmentation. Major Thresholding techniques proposed by different researchers are Mean method, P-tile method, Histogram dependent technique, Edge Maximization technique, and visual technique.

The Mean technique, Pile technique, HDT, and EMT technique on three satellite images in order to select the best segmented image from all above techniques. Experiments and comparative analysis of techniques have shown that HDT (Histogram Dependent Technique) and EMT (Edge Maximization Technique) are the best thresholding techniques which outperform all other thresholding techniques.

The current image segmentation techniques are time consuming and require lot of computational cost in order to perform image segmentation. It is a big problem for real time applications. A new threshold based segmentation method using Particle Swarm Optimization (PSO) and 2-d Otsu algorithm (TOPSO). TOPSO algorithm used PSO technique to search an optimal threshold for the segmentation process. They implement the proposed hybrid method on Matlab 7.0.

F. Region Based Image Segmentation

H. G. Kaganami and Z. Beij [6] proposed the region based segmentation is simple as compare to other methods and also noise resilient. It divides an image into different regions based on pre-defined criteria, i.e., color, intensity, or object. Region based segmentation methods are categorized into three main categories, i.e., region growing, region splitting, and region merging.

A new unsupervised image segmentation method using level set methods and texture statistics. This method is different from other methods since it doesn't assume independent variable, and it doesn't restrict to first order grey features. The implementation includes feature selection step to re-adjust the weights of each feature to get the segmentation. In experiment stage, filter response histogram is used to calculate the number of distributions; Haar wavelet is used to

compute the energy of image wavelet of each band. PDE is used to re-initialize the level sets. Results have shown for a zebra image as correct segmentation.

The new technique was introduced in a region-based image segmentation technique with the help of mean-shift clustering algorithm. Firstly, their method extract color, texture, and location features of each pixel of an image, secondly, make the clusters on the basis of those features using mean-shift clustering approach, label the each region, and finally make segments of image on the basis of these labels.

G. Edge Based Image Segmentation

M. Sarif et al. [7] proposed the edge detection is a basic step for image segmentation process. It divides an image into object and its background. Edge detection divides the image by observing the change in intensity or pixels of an image. Gray histogram and Gradient are two main methods for edge

detection for image segmentation. Several operators are used by edge detection method, i.e., Classical edge detectors, zero crossing, Laplacian of Guassian (LoG), and color edge detectors etc. In this section several new approaches regarding Edge detection based image segmentation is discussed from last ten years.

A new image segmentation technique based on region growing and edge detection method helps the segmentation process to avoid from errors when both techniques used in a separate manner. Region growing is used to find the edge pixels in the image, while 2nd order derivative is used for edge detection. Experiments are conducted on 3D MRI image data. Gaussian technique is used for smoothing after edge detection. Results have shown that their technique is better in order to preserve more edge information.

TABLE I
COMPARATIVE STUDY OF DIFFERENT SEGMENTATION TECHNIQUES

Study	Common Carotid Artery Image Segmentation Technique	Ui	Evaluation Method	Imterror(Mm)	N
[4], [6], [7]	Edge Based Method Using Intensity And Gradient Information Combined With Morphological Smoothing For Inter And Intra Observer Variability Evaluation	Yes	Mean Distance	0.04 +/- 0.007	50/300
[4], [6], [7]	Edge Based Method Using A Multi-Step Coarse To Fine Gradient Based Method That Incorporates Intensities, Gradients And Pixel Continuity	Yes	Mean Distance	0.016 +/- 0.0387	45
[2]	Multi-Scale Dynamic Programming For Finding A Global Optimum Cost Function, Incorporating Different Image And Geometrical Features	Mc	Mean Distance	0.042	50
[2]	Edge Based Method Combining Gradient Evaluation (Macleod Filter) Followed By Feature Enhancement Combined With Dynamic Programming That Incorporates Additional Anatomical Information	Yes	Mean Distance	0.1154	275 Images
[5]	Scale-Space Multi-Resolution Analysis That Involves Speckle Filtering And Smoothing Followed By Mean Shift Clustering For Estimation Of The Density Gradient And Boundary Reconstruction	No	Mean Distance	0.039+/-0.186	300 Images
[1]	Edge Analysis Provides The Input For Hough Transform On Continuous Image Segments Where Dual Snakes Provide The Final LI And MA Outlines	Yes	PD Mean Distance	0.038+/-0.0164	50 Images
[2]	Spline Fitting On Evaluated Edges, Followed By Dynamic Programming Where The Final Segmentation Is Smoothed Using Geometric Active Contours	Yes	Mean Distance	0.07+/-0.11	24/47
[5]	Inter-Greedy Technique Fusing Different IM Segmentation Methods Including Signal Processing, Snakes, And Watershed Segmentation	No	Mean Distance	0.0463+/-0.469	200

Aic Automatic Initial Contour, Ui User Interaction, Mc Manual Correction Possible, N Number Of Cases/Images, Li Lumen Intima, Ma Media Adventitia, Pd Polyline Distance.

H. Fuzzy Theory Based Image Segmentation

S. Naz et al. [8] proposed the fuzzy set theory is used in order to analyze images, and provide accurate information from any image. Fuzzification function can be used to remove noise from image as well. A gray-scale image can be easily transformed into a fuzzy image by using a fuzzification function. Different morphological operations can be combined with fuzzy method to get better results. Fuzzy k-Means and Fuzzy C-means (FCM) are widely used methods in image processing. A new fuzzy rule based image segmentation technique was incorporate with the spatial relationship of the pixels. Three types of membership functions are used, i.e., Membership function for Region pixel distribution, to measure the closeness of the region, and to find the spatial relationship among pixels. There is no need to define parameters in their technique, like FCM algorithm. Fuzzy rules uses above three membership functions and fuzzy IF-THEN rule structure to perform segmentation of an image. FCM and proposed technique is implemented on Matlab 5.3.1 on X-ray image and human vocal tract image. Results have shown that GFRIS

outperform FCM and isolate the object from background accurately.

III. CONCLUSION

Thus the segmentation and tracking methods used to measure the thickness value. Using the proposed automation algorithm it is real time quick examination. It provides low cost or economic and non-radiation and time reduction. The automation process will reduce the human faults. The all results are shown in Table I.

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