

Automated Algorithm for Carotid Lumen Segmentation and 3D Reconstruction in B-mode images

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Abstract

The B-mode image system is one of the most popular systems used in the medical area; however it imposes several difficulties in the image segmentation process due to low contrast and noise. Although these difficulties, this image mode is often used in the study and diagnosis of the carotid artery diseases.

In this paper, it is described the a novel automated algorithm for carotid lumen segmentation and 3-D reconstruction in B- mode images.

1 Introduction

The carotid artery is extremely important, in the blood supply to the head and neck zones [2]. Its importance is even greater for the blood supply to the brain, as being one of the most sensitive organs in the organism. The brain needs about 15% of the blood stream and consumes about 20% of oxygen and glucose from the organism, due to its huge demand for energy (ATP) [1]. It works based on an highly oxygenated metabolism and easily suffers disturbance, in the absence of this molecule[1, 2].

The atherosclerosis is one of the pathologies that affect its functions as it slowly reduces the blood supply trough the artery. It is one of the main causes of cerebrovascular accidents, quickly becoming one of the major causes of death in the occidental world [3].

As it is a pathology highly associated to the zone where blood flux is disturbed, the hemodynamics and medical imaging have been studying several ways to detect and understand its process. Previous studies show that the study of velocity in the carotid artery might help to improve the knowledge of this pathology [3]. In order to accomplish this, the design of models capable to support, and simulate these studies is demanded. It is based on these assumptions that we propose a method for a fully automated carotid lumen 3D model reconstruction, using B-mode carotid imaging, one of the cheapest, harmless and most widely used in this medical area [4].

2 Methods

We started by developing an automated approach for detecting lumen points. This approach is based on a straight-line traced inside the lumen and parallel to the horizontal axis, by searching for hipocogenic characteristics on the same direction. Due to previous knowledge of high intensity changes in this type of image, a gradient operator, the Sobel operator, computes its image gradient, which combined with the straight-line inside the lumen, defines automatically region of interest (ROI).

As we can have extremely noisy input images, we only use the strongest gradient points, believing that the majority of the lumen walls are included in the selected set. Although this excludes a huge amount of noise, it has the disadvantage to exclude the weakest lumen walls points defined. In order to overcome this, from the gradient threshold we select along the vertical axis the closest points of the straight-line and applied morphological operators in order to remove small discontinuities. Additionally, to remove the bigger discontinuities, an interpolation system was developed, by linking the terminal points of the remaining wall segments. At the end of this step, the two selected walls might have failures, like a huge vertical variation in a little horizontal range, which are anatomically impossible, or misleads starting points. Another interpolation is performed to fix these failures and the final resultant points are applied to the original image.

For the 3D reconstruction from the segmented contours, 3D circles are building based on the diameters along the segmented lumen.

3 Results

In order to show the results regarding each step of the algorithm developed, three sample images were used, Figures 1-11.

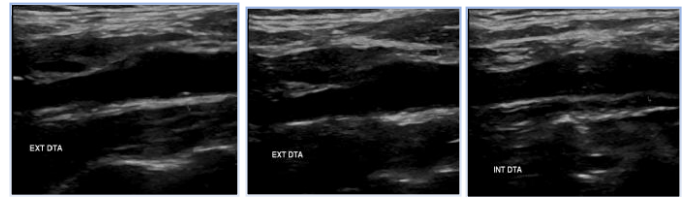


Figure 1 – Three original ultrasound images

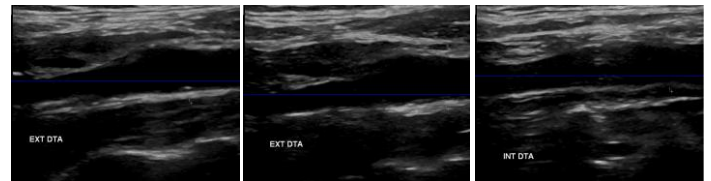


Figure 2 – Lumen straight-line detected

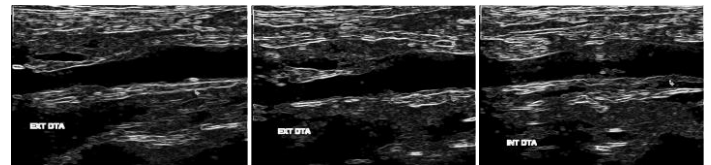


Figure 3 – Gradient Images

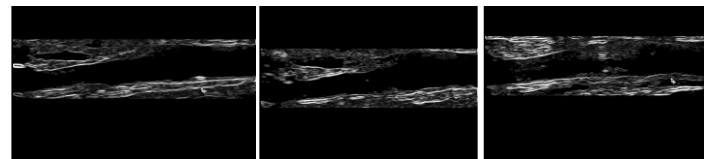


Figure 4 – ROIs defined



Figure 5 – Detected strongest gradient points

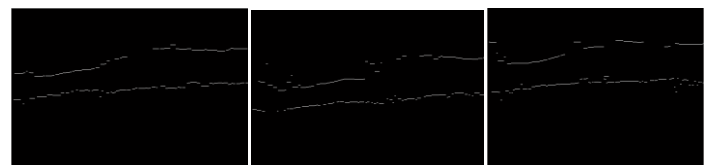


Figure 6 – Detected strongest and closest to the straight-line gradient points



Figure 7 – After removing small discontinuities

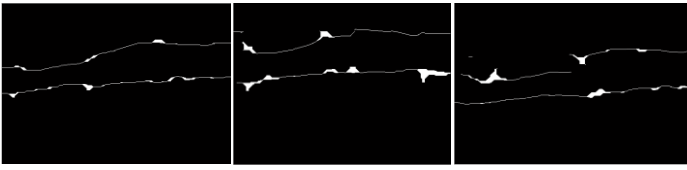


Figure 8 – After the interpolation process to remove larger discontinuities

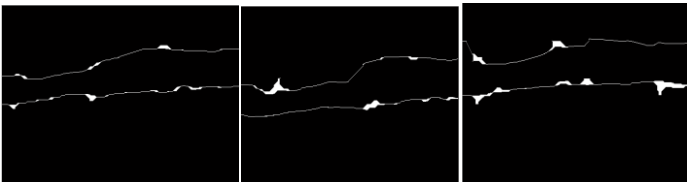


Figure 9 – After fixing the line discontinuities



Figure 10 – Resultant image segmentations



Figure 11 – An example of 3D lumen reconstruction

4 Discussion

From the original Ultrasound B-mode Carotid images (Figure 1), and taking advantage of the horizontal lumen dispositions, all the straight-lines were successfully defined (Figure 2), and the ROIs defined from these lines contained the desirable structures (Figure 4).

After the gradient calculation as expected, a huge amount of noise was present (Figure 3). The majority of the information contained in the ROI is undesirable, which supports the next step of image thresholding. As we can see in Figure 5, the noise component after this step was much lower; however, some of the weakest wall segments were suppressed. Selecting only the closest points to the computed straight-lines along the vertical axis (Figure 6), also helps to exclude undesirable information for the next steps of final definition of the lumen walls.

The application of morphological operators, proved to be a very effective way of solving the smaller discontinuities (Figure 7); however, the larger ones cannot be fixed by using the same method, as it severely distorts all the remaining segments. The use of interpolation, as we can see in Figure 8, avoided these deformations by acting only in the remaining discontinuity zones between segments. After performing all these steps, a few failures were present in some detected wall points. Those failures were caused by two situations: Firstly, the absence of a

starting point in the zero coordinate of the horizontal axis might mislead the connection of the wall to the end of the image, and secondly some huge vertical variances in small horizontal variance, appeared to be very strange to natural shapes. Thus, the fixing step of the algorithm acted effectively by searching those points and correcting them by removal and interpolation of the recently empty area (Figure 9).

The algorithm developed, was successfully applied to the original images, matching well with the hypoechogenic areas in the lumen structures (Figure 10). Also the 3D reconstruction based on the sampling of the segmented lumen, proved to be a very easy way to build a 3D model from the original 2D image, as shown in Figure 11.

5 Conclusions and future remarks

For the available image dataset, although the lack of medical supervision, which prevents the comparison of the defined edges with the medically expected and its validation, we can consider that the results were satisfactory for several reasons: Firstly, and as expected an ultrasound image is extremely difficult to process due to the huge amount of noise and low contrast. The automated location of points inside the lumen is quite a challenge, and it was performed successfully. However it might be interesting to develop solutions in order to adapt the direction of this line according to the disposition of the lumen, as the presented algorithm only works with horizontal aligned structures.

The gradient operator also presented good results, if we consider that the strongest gradient points selected, suited perfectly the majority of removed noise and the guiding lines for the remaining wall definitions. Nevertheless, the Sobel operator is still one of the simplest ways to calculate an image gradient, so it is possible to improve the accuracy of this step, by applying other gradient methods.

The morphological operators, proved to be very effective in the discontinuities. It showed good results without significantly changing the previously defined shapes. However, the interpolation, despite, showing satisfactory results on the bigger discontinuities, added automatically non natural shape errors. And, the bigger the discontinuity, the bigger the error that will be added in the interpolation. An improved gradient definition can improve this step, by reducing the sizes of the discontinuities, and consequently the interpolation errors.

It is proven that when the 2D segmentation is successfully completed, the 3D reconstruction of the data segmented can be easily performed. However, the reconstruction method adopted based on 3D circles can be improved through the building of a polynomial meshing representing the shape of the carotid artery in a more natural way.

6 References

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