A NOVEL SEGMENTATION TECHNIQUE FOR CAROTID ULTRASOUND IMAGES

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ABSTRACT

Ultrasound provides a non-invasive means for visualizing various tissues within the human body. However, these visualizations tend to be filled with speckle noise and other artifacts, due to the sporadic nature of sound waves.

This paper presents a novel segmentation technique for use on noisy B-mode ultrasound images of the carotid artery. This scheme is based on histogram equalization, Canny edge detection and morphology methods. The proposed scheme provides various degrees of customizability, for a wide range of ultrasound images. The experimental results show that this scheme is accurate enough to segment the different textures in ultrasound images. These automatically segmented regions may alleviate the need for a practitioner's time consuming manual segmentation of wanted regions.

1. INTRODUCTION

According to the Canadian Heart and Stroke Foundation, heart disease costs Canada more then $24 billion dollars a year, and this value continues to increase with each passing year [1]. This amount covers the cost of care and research to help alleviate the dreadful effects of this disease. In order to help reduce such costs, techniques to help simplify and reduce a medical practitioner's daily workload need to be developed.

Ultrasound (US) has now been adopted as the defacto standard for inexpensive non-invasive clinical diagnosis of atherosclerosis (the hardening of the arteries). An indication of early symptoms, which can be used as a pre-clinical disease marker, is a thickening of carotid plaque levels. Such plaque levels may block the passage of blood traveling to the upper body and brain. However, plaque and boundary identification in US images is still a tedious and difficult task due to the lack of its automation. Currently, practitioners identify plaque regions and other myocardial tissues in US images by manually tracing their borders to best fit the data.

1.1 Current Research

Several studies are being conducted to improve the quality and detection within US images. Bottalico *et al.* developed a tool that brightens the edges of an artery using a Kirsch Operator [2]. However, their technique fails to generate a contour of the carotid lumens.

Abolmaesumi *et al.* designed an efficient Kalman-star algorithm to estimate the location of the arterial wall [3]. However, their algorithm may not give accurate representation of the external boundaries of the wall due to the use of gradient estimators.

Gill *et al.* devised a segmentation technique to track the progression of ulcerated plaque [4]. Their scheme used region growing or more specifically, balloon modeling [5]. This practice may prove efficient, however plaque tissues will be included within the identified balloon due to its global mesh structure.

Meo *et al.* used a contour probability distribution (CPD) function in order to evaluate the accuracy of their segmentation algorithm [6]. Their algorithm used entropy mapping and morphological operations based on gray-level properties within an image. These mappings create an accurate identification of the arterial wall. However, they are strenuous on computer systems, resulting in long execution times.

Other edge detection techniques, such as region growing [7] and gradient filters [8] were ill suited due to problems with stopping criteria and local border detection methods, respectively.

In this paper, a new technique is presented in order to help identify carotid regions semi-automatically by segmenting B-mode US images. This technique would dramatically decrease the time needed to analyze the US images. In order to accomplish this segmentation solution, image-processing techniques such as histogram equalization, Canny edge detection and morphology, have been used to manipulate the image data.

1.2 Paper Layout

The rest of this paper is organized as follows. In Section 2, the proposed scheme will be broken down into modules. These modules will be explained thoroughly. The results of the scheme will be shown in Section 3, and Section 4 will contain conclusions.

2. SYSTEM AND METHODS

US speckle noise makes it increasingly difficult to define the lumen boundary when poorly visualized. This effort is further hindered by the occurrence of lipid-rich plaque or a poorly angled transducer during image acquisition. Unfortunately, there is no magic way of completely canceling these troubles (short of not acquiring the image to begin with).

Hence this research [9] an attempt to overcome some of the inherent problems within US imaging is presented. This is done so in a series of steps to define and detect the lumen wall:

Step 1 Histogram equalization [10] is applied as a preprocessor step.

Step 2 Canny edge detection [11] is applied to extract the needed edge data.

Step 3 Morphological operation [12] is applied to the images in order to create a closed contour of the wanted lumen boundaries.

Step 4 Boundary extraction scheme [12] is used to give a concrete contour of the plaque wall.

Step 5 Image composition is achieved by layering the edge-detected image on top of the original, or histogram-equalized, image for further analysis.

These steps comprise the presented scheme; also depicted in the block diagram of Figure 1. In the following subsections, each of these steps will be explored and explained in greater detail.

2.1 Histogram Equalization

Currently, US images have many inherent problems, including speckle noise, interference and have the tendency to be extremely low in contrast. This is a result of the US data acquisition system used to spawn the data.

A histogram of an image represents the frequency of a particular gray level used throughout an image. The histogram equalization method permits the stretching of gray levels across an image. It maps the image gray values such that the resulting histogram will be evenly distributed.

While this technique increases the contrast of the image, it also causes an increase in the inherent speckle noise within the US image as well. However, the next step will resolve this issue.

2.2 Canny Edge Detection

In this step, Canny's edge detection algorithm will first smooth the data (by means of a Gaussian filter) and then perform edge detection. Canny optimizes edge response with respect to three criteria:

- *Detection*: real edges should not be missed, and false edges should be avoided.
- *Location*: the edge response should lie as close as possible to its true location.
- *One response*: a true edge should not give rise to more than one response.

However, Canny is particularly susceptible to its input parameters [11]. These parameters allow for fine-tuning of the edge-detection mechanism, permitting the user to acquire the desired results on an image data set. The parameters used for the carotid artery US images were empirically chosen to be geared for the highest degree of accuracy.

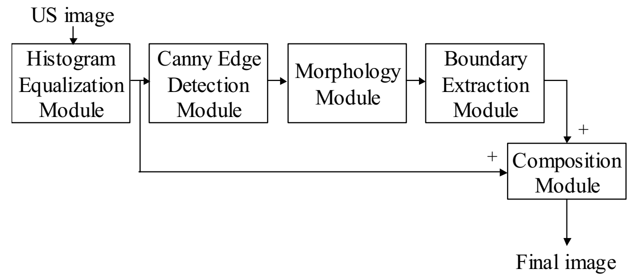

Figure 1. Block diagram of proposed scheme

The Canny algorithm uses a technique called "*non-maximum suppression*" that relies on two thresholding values (lower and upper). Canny recommends a ratio of 1:3 to be used in order to attain the best results. For US images, a 30% lower threshold is selected, while a 90% upper threshold is selected. Empirically, we found that these values give accurate representations of the true edges of the artery while helping to eliminate the creation of false lines due to speckle noise in the image.

2.3 Morphology

In this step, morphological operators are used as a postprocessor in order to clean the edge dataset generated by the Canny edge-detection algorithm. Gaps and holes in the plaque contour can be eliminated and sealed by using a morphological opening function.

Various structuring elements may be used to close the contour. When using morphological opening with the US images presented, a structuring element (SE) of size seven-by-seven with rounded corners is used. The seven-by-seven SE provides the necessary size to seal the plaque contour on the B-mode US images presented. Rounded corners give a better representation of smooth lines since the SE is actually a circle (i.e., giving it the ability to roll around the edges). This SE may be modified if the contour gaps generated by the Canny edge operator are large. The SE can be modified using the derived Equation 1,

$$\varepsilon = (\omega * 2) + 1, \qquad \textbf{(1)}$$

where ε represents the SE size, and ω represents the maximum pixel gap, which signifies the greatest size width of the gaps in the contour.

2.4 Boundary Extraction

Following the opening of the image, boundary extraction is applied also via image morphology. This is accomplished by using an erode function, with a structuring element of three-by-three in size, and by subtracting this resulting image from the non-eroded contour image, as shown in equation 2,

$$\text{Boundary Extraction}(A) = A - (A \ominus B), \qquad \textbf{(2)}$$

where B represents a three-by-three structuring element, "$\ominus$" represents erosion, and "–" represents the set difference. A three-by-three structuring element is used to dilate the edges by one pixel and then remove the original (hence leaving a one pixel border).

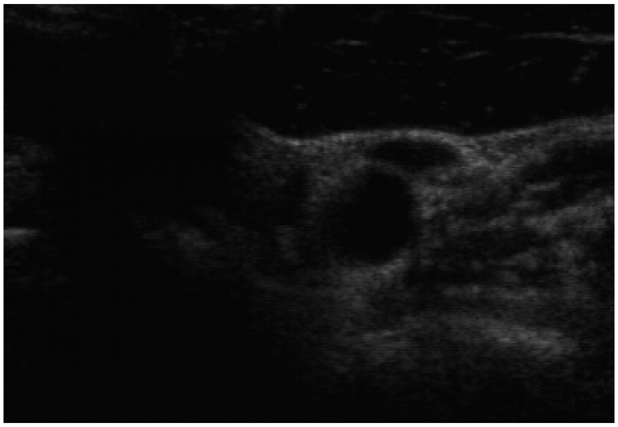

Figure 2. Original B-mode US Image

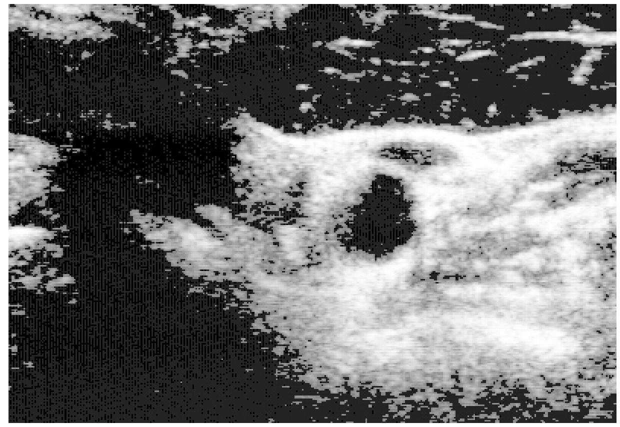

Figure 3. Histogram Equalized B-mode US Image

2.5 Image Composition

The final contour is superimposed on the original image or a histogram-equalized version of the image for the practitioner's review. The desired segmented region can be selected and further examined.

3. RESULTS

For this study [9], a series of B-mode US cross sectional images of the carotid artery have been used. These images were acquired using a 3D US acquisition system (Ultramark 9 HDI US machine and L10-5 linear array transducer). The transducer was attached to a computer-controlled mechanical linear mover. The mover relocated the probe (transducer) horizontally across the neck (at a constant velocity). The US video frequency feed from the transducer was digitized by a high-speed frame grabber and was saved to disk. Hence, the 3-D US bank of images was composed of fixed interval sequential frames taken at a constant velocity of the US transducer.

A data bank of 2644 high-resolution ultrasound images (no less than 400 pixels by 250 pixels each) of the carotid artery was acquired. These images have been chosen to represent a wide range of scenarios. They include individuals with high and low plaque areas within the carotid artery. Many of the images are also taken at different angles and directions (or voxel positions) to provide greater variability on the testing set. Figure 2 shows an example B-mode US image. Note that the image contrast and visibility is extremely low.

Figure 3 shows a histogram equalized B-mode US image depicted in Figure 2. The contrast has been boosted and the gray levels evenly distributed.

Figure 4 shows the histogram-equalized image after applying Canny edge detection. True contours are discovered, while speckle noise is drowned out. Figure 5 is generated by applying the morphological opening operator on Figure 4 in order to create a closed contour. Figure 6 shows the segmented boundaries extracted from Figure 5. Finally, in Figure 7, the extracted boundaries are superimposed on the original image. Figure 8 is the same image with the segmentation results superimposed on a histogram-equalized image.

Area '*Z*' in Figure 7 and Figure 8 accurately defines the location of the carotid lumens (plaque contour) for the artery. Notice the thin transitional segment (in Figure 7 and Figure 8) representing the non-homogeneous portion of the image surrounding this '*Z*' region. This non-homogeneous region, and others like it, is an area of doubt (where possible plaque regions reside) that must be examined by the practitioner. Hence, the practitioner may select the contours that are desired after the scheme has fully completed its cycle.

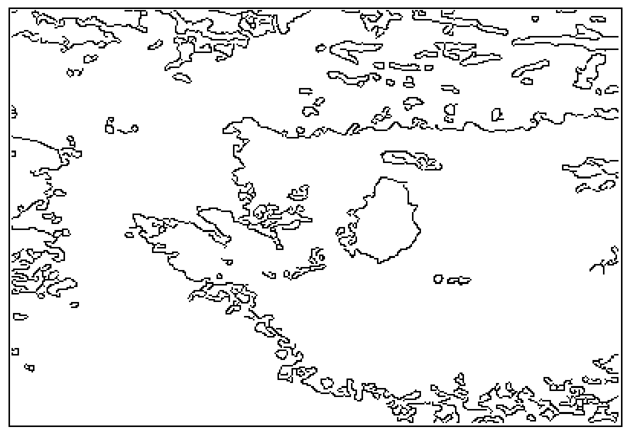

Figure 4. Canny Edge Detected B-mode US Image

Figure 5. Morphological Opening on B-mode US Image

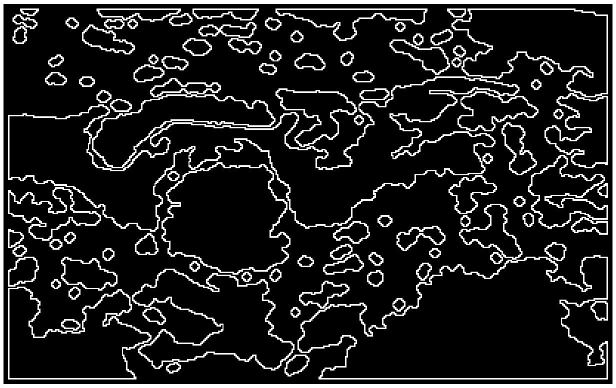

Figure 6. Extracted Boundaries of US image

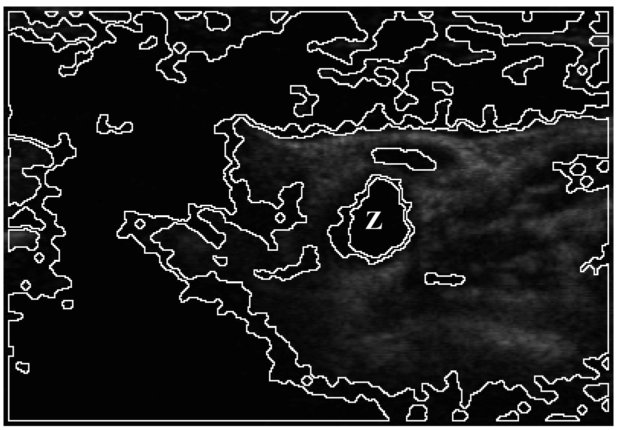

Figure 7. Segmented regions superimposed with US image

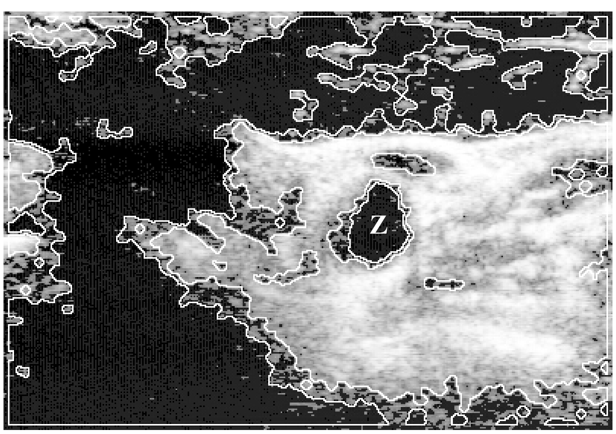

Figure 8. Segmented regions superimposed with Histogram Equalized B-mode US image

4. CONCLUSIONS

In this paper, a novel approach to segment ultrasound images is presented. This approach attempts to overcome the inherent difficulties of ultrasound images, such as speckle noise and artifacts, by utilizing image processing techniques, such as histogram equalization, Canny edge detection and morphology. The proposed scheme takes advantage of the characteristics of B-mode US images by tuning Canny, in order to achieve a greater degree of precision when segmenting.

The results show that the presented technique accurately segmented the US image of the carotid artery. The segmented regions represent different texture sets that help to classify various textural areas of the image, such as the carotid artery and surrounding myocardial tissue. Possible plaque regions are also highlighted. This technique may simplify the job of the practitioner by eliminating the need for manual segmentation.

5. ACKNOWLEDGEMENTS

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