

# BLOOD FLOW GENERATION IN B-MODE ULTRASOUND IMAGES OF THE CAROTID ARTERY

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## ABSTRACT

This paper presents a new blood flow detection scheme, where a novel painting segmentation algorithm is utilized in order to achieve the accurate area of lumens within carotid artery B-mode ultrasound images. The scheme allows for user-defined thresholding providing tolerance levels within the contour detection process in order to overcome crippling interference noise and degrading artifacts in ultrasound images. Since plaque buildup obstructs the flow of blood in the carotid artery, this scheme can identify these severe plaque-thickened inflamed regions, through detecting high and low levels of blood flow.

## 1. INTRODUCTION

### 1.1 Plaque in the Carotid Artery

An elevated level of plasma cholesterol, or Low-Density Lipoprotein (LDL) cholesterol, is an early warning for the development of atherosclerosis (the hardening of the arteries). An indication of atherosclerosis's 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. In many cases, high plaque levels may also cause clots to crust off and travel through the artery where it is susceptible to cause a blockage at another predisposed location resulting in a stroke. Hence, detection and identification of carotid plaque has its due merits.

### 1.2 Ultrasound Images

Several types of ultrasound (US) (e.g., brightness mode, Doppler) have proven to be useful tools for medical imagery [1][2][3][4]. In this study we will be focusing on

brightness mode (B-mode) ultrasound. High-resolution B-mode ultrasonography greatly improves the ability to identify high plaque regions over other techniques (such as invasive surgery). A B-mode US image is made up of a two-dimensional ultrasound display composed of bright dots representing the ultrasound echoes. The echo amplitude determines the brightness of each dot. Since ultrasonography is a non-invasive technique, it provides the best means for an efficient clinical measurement of patients that are susceptible to plaque buildup (whether from diet, genetics, obesity, etc). It also provides the ability to do offline testing on patients, i.e., the US images can be acquired by the physician and stored for later testing, with minimal user input.

### 1.3 Plaque in Ultrasound Images

Carotid plaque is a fat deposit that forms raised patches within the inner lining of the arteries. In ultrasound images, hard and soft calcified regions are represented as a range of high and low contrast white pixels. However, these areas are virtually identical to the surrounding myocardial tissue. This poses many difficult problems for plaque detection algorithms. Yet, there is no need to specifically identify plaque. Rather, by identifying the regions of constrained flow, we may deduce that it contains the highest probability of increased plaque levels or some other major inflammation of the carotid wall.

### 1.4 Current Research

Abolmaesumi *et al.*, in [4], designed an efficient Kalman-star algorithm to estimate the location of the arterial wall. However, their algorithm still crosses the external boundaries of the wall due to the use of gradient estimation.

Gill *et al.*, in [5], devised a segmentation technique to track the progression of ulcerated plaque. Their scheme uses region growing, or more specifically, balloon modeling. This practice may prove efficient, however it

may exclude areas of the plaque tissue within the identified balloon due to its mesh structure.

Meo *et al.*, in [6], used a contour probability distribution (CPD) function in order to evaluate the accuracy of their segmentation algorithm. Their algorithm employed 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.

Abdel-Dayem *et al.*, in [7], proposed a new scheme for carotid artery contour extraction based on the use of morphological operations. Hamou *et al.*, in [8], also proposed a scheme for extracting the contours of the carotid artery on ultrasound images based on the Canny's edge detection scheme. However, these two schemes are used globally throughout an image.

Other edge detection techniques [9], such as region growing and gradient filters, were ill suited due to problems with stopping rule criteria and the sensitivity to noise, respectively.

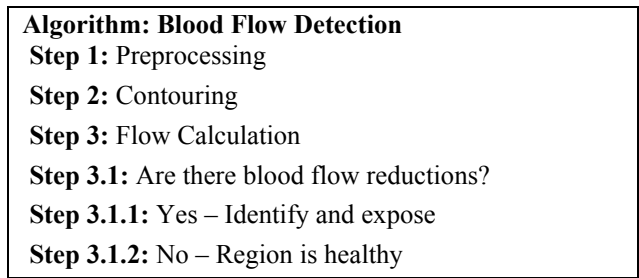
In this paper, an algorithm that employs a painting method, which inspects each pixel thoroughly, is used in order to overcome the many pitfalls of the above techniques.

## 1.5 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

The proposed scheme is broken down into a series of modules, *preprocessing* (to remove noise generated from acquiring ultrasound images), *contouring* and *flow calculation* (to specify where dangerous areas of low blood flow occur), (see Figure 1).



**Figure 1:** Step-diagram of the blood flow detection algorithm

## 2.1 Preprocessing

In the proposed system, US images are acquired through conventional means and hence suffer from normal interference that exists in the imagers. Before detecting the amount of blood flowing within the carotid arterial wall, background noise from the image acquisition process must be eliminated, or at least reduced. To do so, a median spatial filter is applied to the images. By enlarging the filter window-size, a greater smoothing effect is applied to the image. However, doing so eliminates the well-defined edges of the carotid lumen that we wish to preserve. On the other hand, reducing the filter window-size preserves these edges. However, much of the speckle noise that exists within the images is not filtered out.

## 2.2 Contouring

Contouring is accomplished by means of a painting algorithm (see Figure 2). First, we must specify a threshold value to protect against speckle noise that may still exist depending on the size of the median filter used in the previous preprocessing module. Once a threshold value is chosen, the scheme uses this value as its upper and lower tolerance of the gray-values within the carotid artery.

The operator must also select a seed point that exists within the carotid artery. This point will grow in both horizontal directions (i.e., left and right) until it intercepts the internal boundaries specified by the threshold function of the arterial wall, generating our initial line, see Equation (1).

$$x - \text{threshold} < \text{pixel} < x + \text{threshold} \quad (1)$$

where  $x$  is the intensity of the seed point.

This line is pushed onto the *checking stack*. Another needed structure for storing lines is called the *line depository*. This will store the lines already cross-referenced within the desired region for flow calculation.

The painting algorithm then verifies the cascading horizontal lines accumulated on the *checking stack* and checks for adjacent lines (above and below) in sequence. Within each line, each pixel point must satisfy Equation (1). This step must occur when acquiring new lines above or below the checking line (Step 4.4.3 and Step 4.4.5). Once the checking stack is empty, the resulting object will be defined in the *line depository*. The line depository contains the same number of extracted contour objects as the number of image slices; one for each image slice. This assures that the entire region within the arterial wall is detected.

**Algorithm: Painting**  
**Input:** images *imageslices*;  
integer *threshold*;  
pixel location *P.initial*;  
**Output:** series of lines *linedepot*;  
**Variables:** image *I.slice*;  
line *L.initial*, *L.check*, *L.above*, *L.below*;  
stack of lines *checkStack*;

**Step 0: BEGIN ALGORITHM**  
**Step 1:** GET a value from the user and ASSIGN it to the *threshold*  
**Step 2:** generate a tolerance level from the *threshold*  
**Step 3:** GET a pixel location from the user within the carotid artery and ASSIGN it to *P.initial*  
**Step 4:** WHILE (not all *imageslices* processed)  
**Step 4.1:** GET an image from *imageslices* and SET *I.slice*  
**Step 4.2:** Generate a horizontal line *L.initial* from *P.initial* in *I.slice*  
**Step 4.3:** PUSH the line *L.initial* onto *checkStack*  
**Step 4.4:** WHILE (the line *L.check* is on *checkStack*)  
**Step 4.4.1:** POP a line *L.check* from *checkStack*,  
**Step 4.4.2:** STORE the line *L.check* line onto *linedepot.currentSlice*  
**Step 4.4.3:** ASSIGN the line below *L.check* to *L.below*  
**Step 4.4.4:** IF (the line *L.below* is not on *checkStack* or *linedepot.currentSlice*)  
**Step 4.4.4.1:** PUSH *L.below* onto *checkStack*  
**Step 4.4.5:** ASSIGN the line above *L.check* to *L.above*  
**Step 4.4.6:** IF (the line *L.above* is not on *checkStack* or *linedepot.currentSlice*)  
**Step 4.4.6.1:** PUSH *L.above* onto *checkStack*  
**Step 4.5:** END WHILE  
**Step 4.6:** UPDATE *P.intial* to for next image *I.slice*  
**Step 4.7:** UPDATE *linedepot.currentSlice* to *linedepot.nextSlice*  
**Step 5:** END WHILE  
**Step 6:** END ALGORITHM

Figure 2: Step-diagram of Painting Algorithm

### 2.3 Flow Calculation

This module extracts the region within the artery that allows the passage of blood to flow. The area of the object generated from the contour module is calculated by determining the number of pixels that exist within it. This process is repeated over the entire sequence of the B-mode sliced images in order to generate a blood map (or snake model). From this map, the flow of the blood is calculated based on the rise and fall of the areas within the

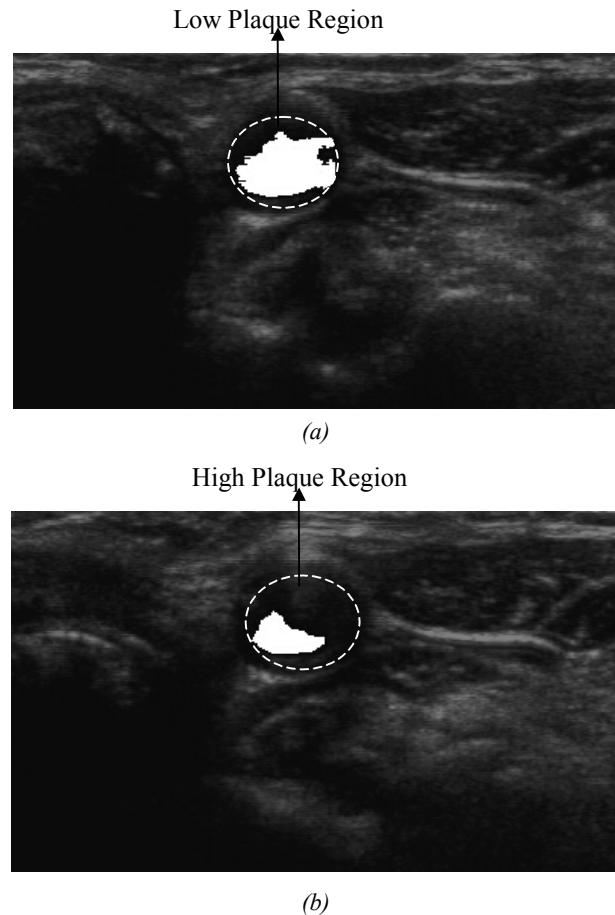


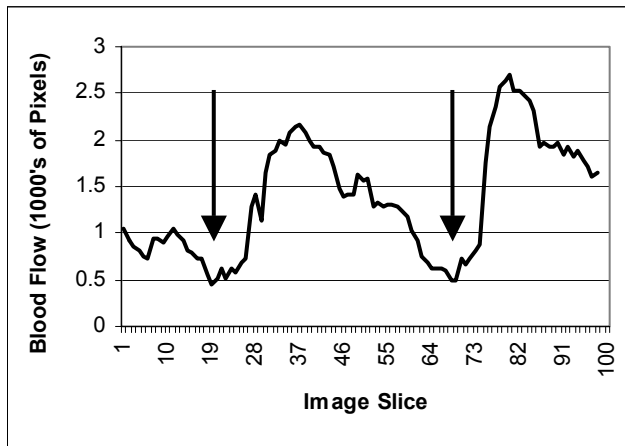
Figure 3: Ultrasound image after applying the painting algorithm. White regions represent blood flow, dotted line represents manually plotted carotid wall. (a) high blood flow region identified (b) low blood flow region identified

detected contour. The series of images that exhibit the lowest amount of flow are identified and presented for the physician's examination.

### 3. RESULTS AND DISCUSSION

Tests were conducted on a series of 98 high-resolution B-mode ultrasound slices of the carotid artery. Empirically, tests revealed that square median filter of 5x5 gives a good compromise between noise removal and edge preservation.

The carotid artery was segmented from its surrounding tissue and highlighted by the scheme for display. Figure 3(a) and Figure 3(b) show regions where blood is free to flow, by superimposing the segmented area with the original image. Both high and low plaque areas are easily detectable since blood cannot flow to such regions.



**Figure 4:** Blood flow in US images. Arrows indicate low flow regions.

The blood flow areas of each ultrasound slice were then recorded and plotted in order to identify which regions are most likely to contain plaque (see Figure 4). High plaque regions are flagged so that the radiologist needs only to examine the necessary areas outlined by the scheme, rather than the entire image sequence.

#### 4. CONCLUSIONS

A painting algorithm with user-defined thresholding is introduced in order to discover where the blood flows within the carotid artery. Large and small median filters are used together to improve the painting algorithms overall effectiveness. We have presented a new method for blood flow calculation from non-invasive B-mode ultrasound images of the carotid arteries. Testing on multiple US carotid artery images shows that this technique can effectively identify blood flow regions within the carotid artery, which gives crucial information to the physician examining the images.

#### 5. ACKNOWLEDGEMENTS

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