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Image processing to delineate the boundaries of peripheral arterial walls

Abstract: The analysis of the arterial wall properties is vital in the prediction of stroke events and arterial hypertension in humans. Numerous researchers have experimented with several approaches to model arterial vessels and to analyse their biomechanical behaviour for many years now. Our study is focussed on image processing of peripheral arterial cross sections to detect and isolate the distinct layers. These boundaries will enable the creation of FEM models for further analysis of arterial wall properties. In a clinical setting, it facilitates doctors to identify the optimum pressure that can be applied to the artery for the treatment of stenosis without damaging the morphology of the blood vessels. This paper aims at distinguishing the various layers of arterial walls from images by minimizing human intervention. Cross section images of arteries from various sources were collected[10][11]. The boundaries from the image were obtained using image processing techniques of MATLAB(R2021a). The approach identified was to convert the input RGB images to grayscale, thresholding and applying morphological operators to delineate the Intima, Media, and Adventitia. These regions of interests (ROI) were then superimposed to generate an image with differentiated boundaries and void of unnecessary noise and inhomogeneity. This approach gave us an insight of the differences in various methods of boundary detection and to infer the optimum approach for accurate demarcation of boundaries of the three layers of arterial walls. It paves a pathway for forward modelling and to perform detailed FEM analysis in in-vitro diagnostics. In a nutshell, it was observed that the edge detection procedure implemented could be used for healthy and stenotic arteries. Further studies must be conducted to test the efficiency across a wide range of images and hence generalise its usage. Upon satisfactory boundary detection, forward modelling could be performed using the identified geometric forms.

1 Introduction

In today's world, due to lifestyle changes, obesity and lack of physical activity are on the rise. Apart from diabetes and smoking[1], obesity is one of the major causes of plaque adhering to the arterial walls, due to the combination of excess calcium and high cholesterol in the blood[2]. This is referred to as arterial stenosis.

Every year more than 2 million people undergo angioplasty and stenting for the treatment of coronary artery disease [3]. Although medical practitioners in clinical setting have various methods and protocols in place to facilitate such procedures, there is a lack of a tool to simulate the ideal pressure required before the actual surgery and to explore how sensor data about wall properties can be interpreted to distinguish various arterial wall conditions.

This paper aims in a first step at creation of refined boundaries from a cross sectional image of an artery, which acts as an input to the FEM modelling system that performs biomechanical analysis[9]. This enables physicians to better comprehend current situation and to determine patient specific optimized parameters well ahead of the surgery.

2 Methods

The first step was to collect cross sectional images (healthy and stenotic arteries) from various sources[10][11]. These images included assorted modalities such as Optical coherence tomography (OCT), ultrasound and microscopic slide images.

The obtained images were then converted from their original form (RGB) to grayscale format. They were subsequently subjected to thresholding and morphological operators[4]. The image segmentation toolbox was then used to create a masked image for the two outer boundaries . For the

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inner boundary i.e., the boundary enclosing the lumen, the "fill holes" operator was applied[5].

These segmented images were then exposed to boundary detection operations[6] which resulted in demarcation of the different ROIs. The output of the ROI is a cell which contains arrays of varying pixel values. These arrays were sorted based on their size i.e., number of elements in a descending order. The arrays with the three highest sizes were chosen and displayed. This resulted in the generation of boundaries void of any noise and inhomogeneity. Refer Figure 1.
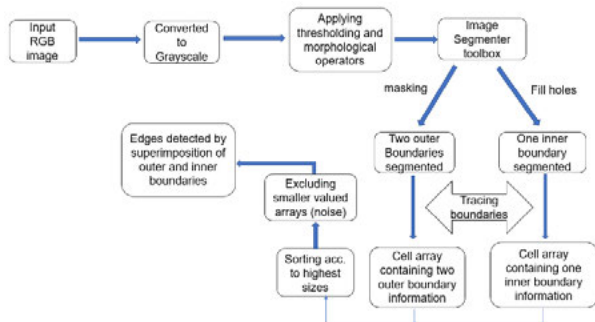

Figure 1: Flow chart representation of the boundary detection technique implemented

These regions were finally superimposed into a single image and displayed as the three layers – Adventitia, Media, and Intima. To evaluate the quality of the results, a comparison was conducted against the existing edge detection functionalities of MATLAB.
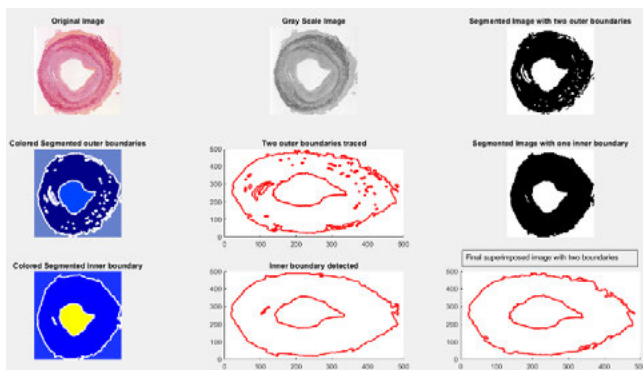
3 Results

The method was tested on a limited data set of images (n=7) and the quality and efficiency of the results were considerably better, when compared to the inbuilt edge detection operators of MATLAB like Canny or Prewitt. It could be noticed that our approach was able to remove approximately 95% of the unwanted ROIs, which are the endothelial cells and connective
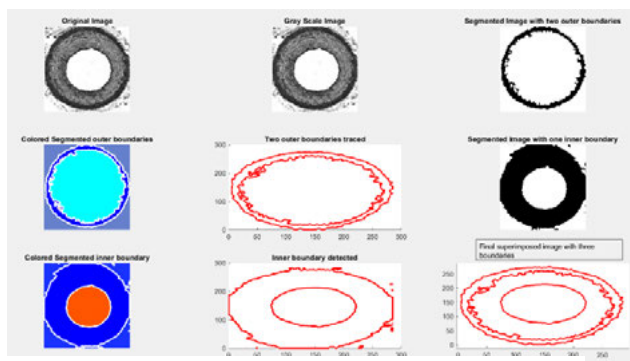
Figure 2: MATLAB output images showing the different phases of boundary detection for a healthy artery

tissues in between the boundaries. As per our expectation the distinct homogeneous boundaries were accurately delineated. Figure 2 illustrates the processing steps and the obtained result when applied to a sample image of a healthy arterial cross section.

This method was also applied to cross sectional images of stenotic arteries. Stenotic arteries are characterized by reduced lumen size due to deposition of fats/lipids in the intima. Figure

Figure 3: MATLAB output images showing the different phases of boundary detection for a stenotic artery

3 shows the result of boundary detection applied to an image showing a stenotic artery. It can be observed that the algorithm detected two boundaries instead of three for the stenotic artery. This is because the original RGB image had no clear demarcation between the Adventitia and Media and hence there is no visible difference in the change of intensities.

In terms of the human involvement, the effort required in fine tuning the algorithm for each input image in contrast to the built-in edge detection operators was substantially lowered by 60%. This reduction in the effort of a human operator would enable proficient diagnostics in a shorter span of time.

4 Discussion

From our analysis of the boundary detection results, images having a high contrast density between the boundaries could be easily identified 90% of the time, using the developed MATLAB code. The efficacy of the code can also be seen, with respect to noise removal and accurate tracing of the ROIs. The inhomogeneity of the arterial structures in between the target boundaries could be almost eliminated.

The first constraint of our research was the limited availability of a wide range of cross-sectional images of arteries with varying colour schemes. The functionality of the code could be tested comprehensively, provided an access to a larger database of OCT/Ultrasound/CT images of stenotic arteries.

The second limitation is that a certain human intervention is required especially in those cases when a precise distinction between the boundaries is not obvious in the image. A fine tuning of the code is required during such instances to obtain the desired output.

Thirdly, scenarios in which the images did not demonstrate an accurate division between the three arterial wall layers, the Image segmentation toolbox functionality of MATLAB allowed the manual selection of the different ROIs varying according to the degree of stenosis or morphological characteristics of the artery. This ROI method provided with a greater flexibility to choose and segment different regions. Although, this method would be predominantly manual.

Consequently, further research on interpreting the biomechanical properties of arteries can be carried out using the boundaries detected. In modern day clinical diagnostics, there is a need to decipher the extent to which the arteries can be subjected to a certain stress before procedures like angioplasty. The results obtained from our boundary detection approach can be utilized by FEM software to facilitate forward modelling[7] and to provide clinicians with the necessary input parameters.

5 Conclusion

To summarize, the edge detection algorithm developed has been able to extract the main boundaries of arteries from cross sectional images. It has also been able to significantly eradicate the inhomogeneity and unwanted noise. The domain of forward modelling via FEM analysis[8] could be benefited from our achieved results. The combination of biomechanical behavioural simulation of arteries with our edge detection technique could prove to be beneficial in the field of in-vitro diagnostics.

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