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Automated Boundary Detection and Measurement of Common Carotid Artery Attributes Using Transversal B –Mode Ultrasound Images

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ABSTRACT

Cardio vascular diseases (CVD) can be predicted by measuring the elasticity and stiffness of any artery and it has been proven to be a strong independent predictor. Various indices have been introduced to quantify arterial stiffness. This paper describes a novel and automated technique for segmentation and boundary detection of common carotid artery (CCA) using transversal B-mode ultrasound images. Numerical attributes are measured from the detected boundary. The main objective of this work is to determine good arterial features based on the attributes to characterize the elasticity and stiffness of CCA. Attributes are measured for each frame and analyzed for minimum two cardiac cycles to see the changes from systole to diastole. Findings of this analysis would be very useful for the diagnosis of abnormalities in the CCA.

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INTRODUCTION

Cardiovascular disease is the first leading cause of death and adult disability in the industrial world (Kyriacou *et al*., 2010). World Health Organization revealed in a recent study that by 2015 almost 20 million people will die from cardiovascular diseases, mainly from stroke and heart diseases. CCA supplies blood to skull, brain, eyeballs, ears and external nose. When the blood supply to parts of the brain is suddenly interrupted, stroke occurs (Wang *et al*., 2009). The diameter of CCA decreases due to increase in the thickness of arterial wall due to plaque deposit. This causes a reduction of the lumen with possible vascular problems and alters the arterial properties elasticity and stiffness (Molinari *et al*., 2012). The intima-media thickness (IMT) of the CCA is widely used as an early indicator of cardiovascular diseases. It is usually measured by using ultrasound imaging (Loizou *et al*., 2011; Molinari *et al*., 2010). As the carotid artery supplies oxygenated blood to the brain, it may be very useful to quantify its stiffness information in the early diagnosis and characterization of vascular diseases such as carotid artery atherosclerosis (Luo *et al*., 2012). Moreover, arterial stiffness is strongly related to atherosclerosis.

Arterial properties estimated from the ultrasound images can be used to assess arterial stiffness and atherosclerosis in the study of CVDs (Larsson *et al*., 2011; Swillens *et al*., 2012). As ultrasound imaging allows noninvasive assessment of the degrees of stenosis and plaque morphology, it is widely used in the diagnosis of atherosclerosis of the carotid artery (Golemati *et al*., 2009). The resolution of diagnostic ultrasound image is significantly limited by speckle noise. The application of edge detection and segmentation algorithms is also limited by speckle noise (Molinari *et al*., 2011; Tsiaparas *et al*., 2011).

Segmentation of atherosclerotic carotid plaque in ultrasound imaging is investigated in several studies (Loizou *et al*., 2007). If the boundary of carotid artery is segmented precisely, then various bio mechanical and anatomical properties of the artery wall can be computed and that may be useful to clinicians to follow the evolution of the atherosclerotic diseases. In the previous work boundary of CCA was extracted using watershed and wavelet transforms. The diameter was measured from the extracted boundary and used for the analysis of plaque deposit in the vessel (Jayanthi *et al*., 2009).

For the segmentation of the carotid arteries, several algorithms have been proposed in ultrasound imaging. But, an algorithm that performs the segmentation based on minimal user interaction is important in the research context (Destrempes *et al*., 2011). As an early indicator of cardiovascular diseases, we are also interested in the segmentation and characterization of CCA. Hence an effort is

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made in this work to segment and measure the properties of CCA for analyzing the changes in arterial properties during a cardiac cycle and correlate the findings with the arterial abnormalities.

MATERIALS AND METHODS

Image Acquisition and Database:

The arterial movements are recorded in the Ultrasound machine Prosound Alpha-10 from Aloka. ProSound Alpha 10 introduces the "Ultimate Compound Technology", setting a new standard in diagnostic ultrasound. The probe used is a multi-frequency probe of range 5-10 MHz. For this application the frequency is set at 7.5 MHz, since the CCA is at a optimum distance from the skin. The probe is placed about 2cm before the bifurcation of the common carotid artery for uniformity in measurement for all the patients. The video is recorded for 2 to 3 cardiac cycles of carotid artery in B-mode at a rate of 15 frames per second. The blood pressure of the patient is also checked and recorded as the changes in arterial stiffness are accelerated in hypertension (Zakaria *et al*., 2010; Gemignani *et al*., 2007).

Boundary Detection:

Boundary of the carotid artery is segmented and detected by performing the following steps using Aphelion™ imaging software suite which is image processing and image analysis software. First the color image is converted to gray image.

Filtering:

A smoothing filter is normally used to compensate for excessive image noise. Here, a Gaussian filter is used. The smoothing effect reduces the impact of noise in the image but also alters the position of the object boundaries for increased radius. For this case, the radius value is chosen as 5 so that the boundary is not altered much. The Gaussian function is given by

$$G_\sigma(x,y)=\frac{1}{2\pi\sigma^2}\quad \exp\left(\frac{-\left(x^2+y^2\right)}{2\sigma^2}\right)$$

σ – Standard deviation

Segmentation of CCA:

Thresholding technique is used to segment the boundary of carotid artery. Global thresholding is the simplest and most widely used of all possible segmentation methods (Delsanto *et al*., 2007). This simple algorithm works well in situations where there is reasonably clear valley between the modes of the histogram related to objects and background. To extract the objects from the background, threshold value T is selected first. Then any point (x, y) in the image at which f (x, y) > T is called an object point. Otherwise the point is called background point. The segmented image g (x, y) is given by,

$$g(x,y) = 1 \text{ if } f(x,y) > T \text{ ; } 0 \text{ if } f(x,y) < T$$

As lumen part is dark; threshold segmentation is performed to identify the dark objects having pixel values in the range of 0 to 25 for this case. Figure 1 shows the filtered and segmented image.

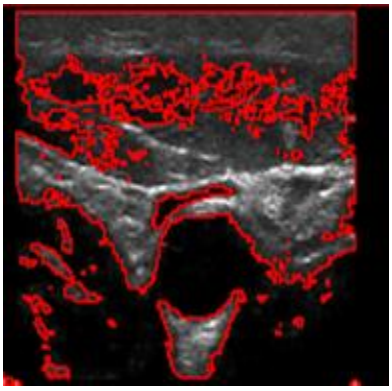

Fig. 1: Filtered and segmented image.

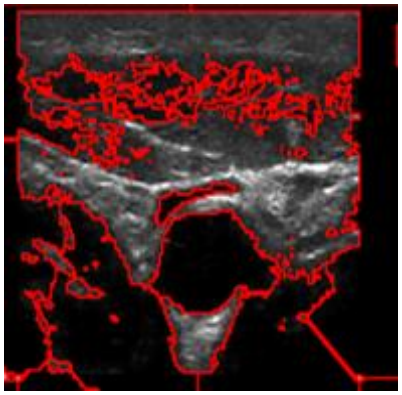

Fig. 2: Splitting touching objects

Split touching objects:

It is found from Figure 1 that the boundary is not segmented precisely as it is touching with other objects in the image. When objects are touching or overlapping in an image, the thresholding process will likely cause them to be segmented as a single object. Such objects need to be split into separate objects. The split touching objects process define a boundary line between touching and overlapping objects transforming the single object into its elementary components as shown in Figure 2.

Hole filling:

A hole is an arbitrary set of contiguous pixels located totally in the interior of an object that are not in the objects boundary. It is found by inspecting Figure 1 that small holes are inside the boundary and they are removed by doing hole filling process. The effect of this process is shown in the Figure 3. Now the boundary of carotid artery is well separated from other objects (Hasegawa *et al*., 2004).

Measurements:

Distension is an important elastic property of an artery. It is the change in diameter of artery from diastole to systole which is equal to one cardiac cycle. Systole refers to contraction of blood muscle and diastole to relaxation. To analyze the elastic property and to characterize the carotid artery, numerical attributes are measured from the detected boundary for each frame using Aphelion TM imaging software suite.

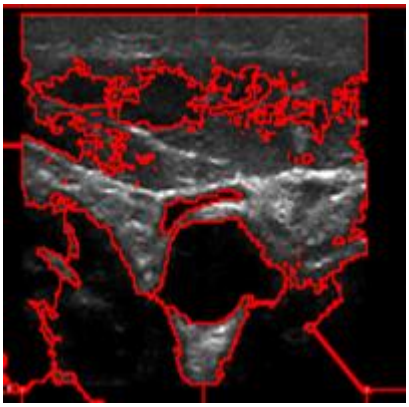

Fig. 3: Hole filling

Numerical Attributes:

Numerical attributes are measurable and scalar values that describe some aspect of an image or segmented object. As the boundary is not a circle and is irregular in shape, the following attributes are measured in this work to quantify the diameter and distension. These attributes are directly related to diameter of the carotid artery.

- Height: It is the difference between the uppermost 'y' coordinate of an object and its lowermost 'y' coordinate, plus one. It gives the vertical diameter of the boundary.
- Width: Horizontal Diameter is given by this attribute. It is the difference between the rightmost 'x' coordinate of an object and its leftmost 'x' coordinates plus one.
- Equivalent diameter: It gives the diameter of the circle whose area is equal to the area of the boundary.
- Area: It gives the value of area inside the boundary.
- Elongation: This attribute is the absolute value of the difference between the inertias of the major and one minor axis, divided by the sum of these inertias. The minor axis is defined as the perpendicular axis to the major axis. This measure is zero for a circle and approaches one for a long and narrow ellipse. It gives details related to the shape of the boundary.

RESULTS AND DISCUSSION

Segmentation Results:

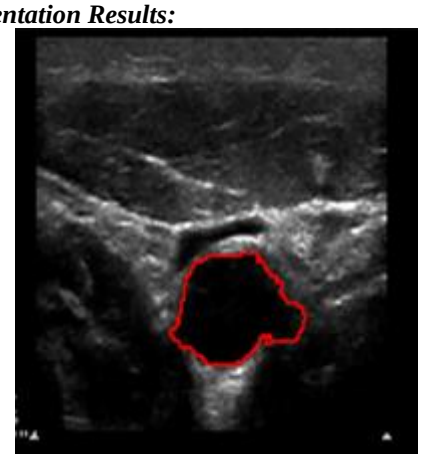

Fig. 4: Boundary of CCA.

The boundary of CCA is detected from the segmented image and shown in the Figure 4. It is obvious from the figure that the detected boundary is irregular in shape and not a perfect circle. CCA video of a healthy subject with a length of 5 second is converted into images at the rate of 15 frames per second which is equal to the source rate. The proposed segmentation algorithm is applied on 30 images obtained from the video and boundaries are detected. As the normal cardiac cycle time is 0.8 second and it varies in between 0.75 to 1 second, 30 images are sufficient to analyze the arterial properties in two cardiac cycles.

Measurement Results:

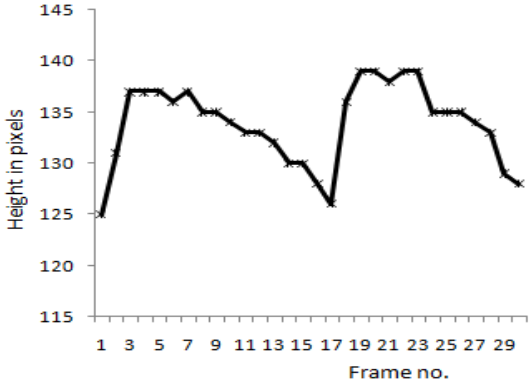

Fig. 5: Variation in boundary height.

From the detected boundary, numerical attributes height, width, equivalent diameter, area and elongation are measured for all 30 images. Variation of these attributes with respect to the frame number is plotted and analyzed. The values of height, width, equivalent diameter, area are given in number of pixels and values of elongation are constant in between 0 and 1. Figure 5, shows the variation in the height of the boundary for more than two cardiac cycles. Variation of width and equivalent diameter

are shown in the Figure 6 and 7 respectively. Change in the values of the attributes area and elongation for 30 images covering two cardiac cycles is given in the Figure 8 and 9 respectively.

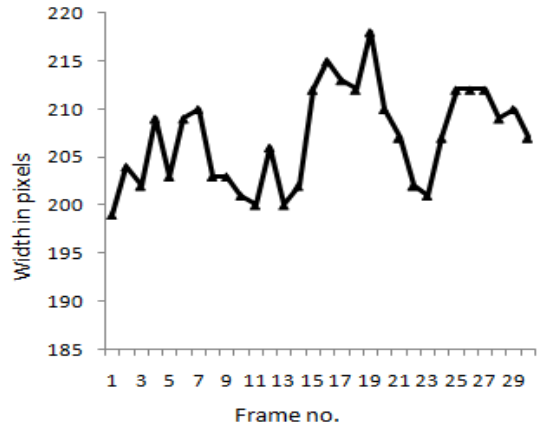

Fig. 6: Variation in boundary width.

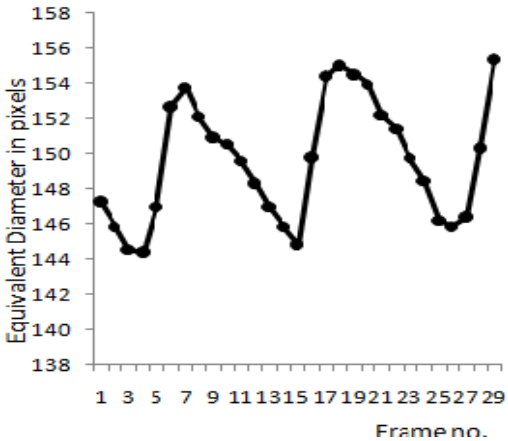

Fig. 7: Variation in equivalent diameter

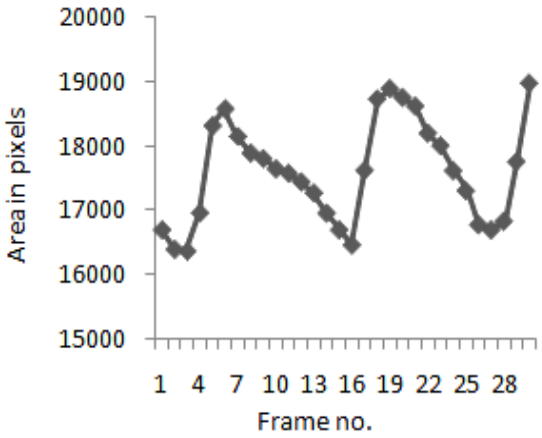

Fig. 8: Variation in boundary area.

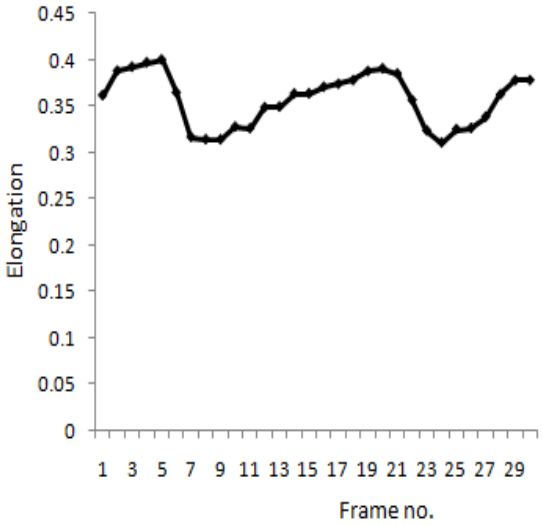

Fig. 9: Variation in elongation.

By analyzing the variations in the values of attributes measured from the detected boundary for two cardiac cycles, it is found that all the four attributes height, equivalent diameter (ED) , area and elongation except width increase and decrease between the peak and valley points. This is due to the fact that CCA contracts during systole and expand or relax during diastole. Systole takes one third of cardiac cycle time whereas diastole takes two third. This statement is true only for ventricular systole and diastole and it is reverse for atria. The atrial systole takes two third of cardiac cycle time and atrial diastole takes one third. Because the cardiac cycle only focuses on events occurring in the ventricles and always atria and ventricles go through separate cycles of systole and diastole. This fact is observed in the plots of variation in the values of area, height and equivalent diameter of CCA by taking the number of frames from valley to peak and from peak to valley into consideration.

During the expansion or relaxation of CCA, the values are increasing and number of frames is less which is approximately equal to one third of total frames in a cardiac cycle. During contraction, the values are decreasing and number of frames is more which is approximately equal to two third of total frames in a cardiac cycle. The peak and valley points are identified from the plots and the minimum and maximum values of variation in the attributes are given in Table 1. The value of elongation varies between 0.3 and 0.4. It increases during atrial systole and the shape of boundary approaches to an ellipse as the CCA contracts. During atrial diastole, its value is decreasing and the shape approaches to circle as CCA relaxes. Variations in the width of the boundary are not similar to other attributes, though it has peak and valley points. The variations in the attributes given in the Table 1 are for a healthy subject and they can be used to classify the normal and abnormal CCA. Measurement results clearly show that the

numerical attributes obtained from the detected boundary are highly related to distension.

Table 1: Variation in numerical attributes.

Attribute	Min Value	Max Value	Variation
Area	16371	18974	2603
Elongation	0.3	0.4	0.1
E D	144	155	11
Height	125	139	14
Width	199	218	19

CONCLUSION

A method is proposed to characterize the elasticity and stiffness of common carotid artery with good arterial features by detecting the boundary and measuring the numerical attributes using transversal B-mode ultrasound images. The boundary is segmented and detected by applying thresholding technique. From the detected boundary, numerical attributes height, width, equivalent diameter, area and elongation are measured and plotted for 30 images obtained from a healthy subject. The variations in the values of the attributes are observed for more than two cardiac cycles. It is found that the variations follow the behavior of common carotid artery during systole and diastole. The measured attributes have excellent correlation with distension and these can be used to quantify the elasticity and stiffness of CCA. Variation of attributes between the peak and valley points can be used as an indicator to detect arterial stiffness since the variation is directly proportional to elasticity and indirectly proportional to stiffness.

Risk factors such as cholesterol, blood pressure, smoking and diabetics correlate to the arterial stiffness and CVDs. If the measurements are related to these risk factors, it would be very useful for the prevention of CVDs. Future work will focus on further testing of the proposed method in a larger image dataset considering all these risk factors to validate the good features to detect abnormalities in the common carotid artery and classify the healthy and unhealthy subjects.

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