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EXPLORING ULTRASOUND IMAGES OF THE CAROTID ARTERIES USING NEURAL NETWORK TOOLS

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ABSTRACT

This work aims at 3D model reconstruction and hemodynamic analysis of carotid bifurcations based on hospital ultrasound images. The suggested approach addresses B mode image segmentation as a pattern recognition problem and boundary velocity conditions are extracted from Doppler PW mode velocity data. Both tasks are solved using a combination of artificial neural network (ANN) tools. The development of an integrated technique for geometric reconstruction, structured meshing, blood flow simulation and hemodynamic analysis of the carotid bifurcation enables the quantification of the degree of stenosis and promotes the understanding of how hemodynamic factors are involved in atherosclerotic disease.

Keywords: ultrasound imaging, carotid bifurcation, artificial neural network, flow simulation.

INTRODUCTION

Strong hemodynamic stresses are closely related to the development and progression of atherosclerosis and subsequent circulatory disease. An important site for arterial disease development is at the origin of the internal carotid (IC) artery (Santhiyakumari and Madheswaran, 2008). In this sense, hemodynamic conditions of the carotid artery bifurcation are considered a reliable indicator of plaque formation, resulting in transient ischemic attacks or strokes. Aged or diseased carotids can exhibit a variety of deformations and tortuous morphologies that exhibit significant departures from an idealized case (Menchón-Lara et al, 2014). Accurate and efficient measurements of the carotid geometry have been successfully obtained using ultrasound imaging (Loizou, 2014). To generate the numerical model, the gray-scale (B-mode) images are processed to manually remove small branching vessels and the lumen geometry segmented in order to obtain cross-sectional contours (Santos et al, 2013). Using pulsatile inlet conditions based on Doppler measurements of blood velocity, carotid bifurcation numerical simulations can predict complex flow field, turbulence and distribution of the biomechanical stresses present within a stenosed carotid artery.

THE PROPOSED APPROACH

Ultrasound imaging is an attractive technique due to its noninvasiveness. The major negative aspects of ultrasound images are their poor quality, presence of speckle noise, and wave interferences. Thus, a computer-aided technique for carotid artery ultrasound image analysis is highly desirable (Chaudhry et al. 2012). Most of the techniques require user intervention at certain level.

The proposed scheme consists of the following steps: dataset acquisition, preprocessing, carotid artery image segmentation, feature extraction and modelling. The graphical representation of the proposed approach is shown in Fig. 1.

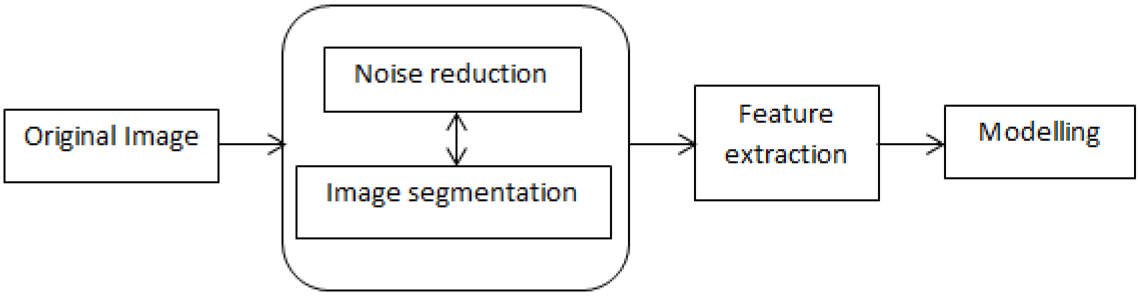

Fig. 1 - Flow chart of the proposed approach

For image pre-processing a median filter has been used for noise removal because in case of carotid artery ultrasound images, it has been observed that by diminishing noise it preserves image details in better way as compared to average and bilateral filters (Castro et al. 2014a). During experiments images are not aligned. It is due to the fact that not only during imaging process acquisition ultrasound transducer has continuously been moved around the carotid artery but also due to patient movement. Ultrasound transducer and patient movement thus result in images which may not be aligned. It is easy for a human expert to locate the region of interest and obtain measurements. However, automatic detection by computer requires aligned images for accurate identification (Castro et al. 2014b). The main objective of image alignment is to present two or more images in the same orientation. Usually, one of images is taken as a reference image. One of the possible approaches to align the images is the use of control points also called corresponding points. An iterative process to select the control points in input and reference images requires user intervention.

Objects in the carotid artery ultrasound image are to be separated from background. A histogram based algorithm calculates an optimal threshold to separate objects by considering it as a two-class problem. Some noisy patterns may remain and have to be removed by morphological opening operations. Accurate segmentation of carotid artery ultrasound images using active contour approach greatly depends upon the window initialization. If initialization is done well, one can get significant results. As shown in Fig. 2 lumen thresholds are used to fill in the initial lumen contour to drive the previous initial contour towards the boundary of the region of interest.

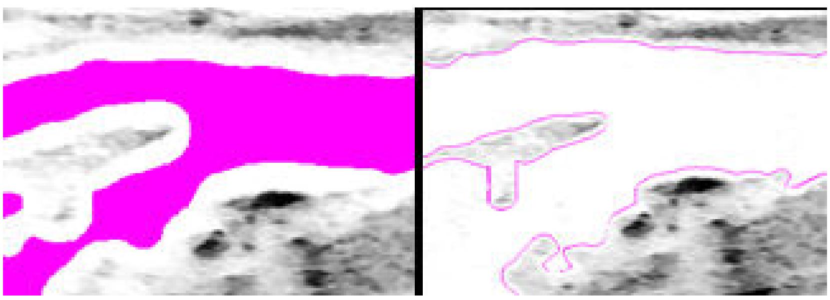

Fig. 2 - Segmentation approach methodology: (left) lumen identification; (right) final contour

Location and size of window defining the initial area inside the artery walls vary from image to image depending upon the objects in the carotid artery ultrasound images. Once the window is determined, an active contour method can successfully be applied to segment the carotid artery ultrasound images. Images may become rotated, sheared, and translated during ultrasound imaging acquisition. Such images are required to be aligned before by incorporating spatial information for control point selection in the form of better registered image. The spatial information helps to correlate base and input image control points as shown in Fig. 3.

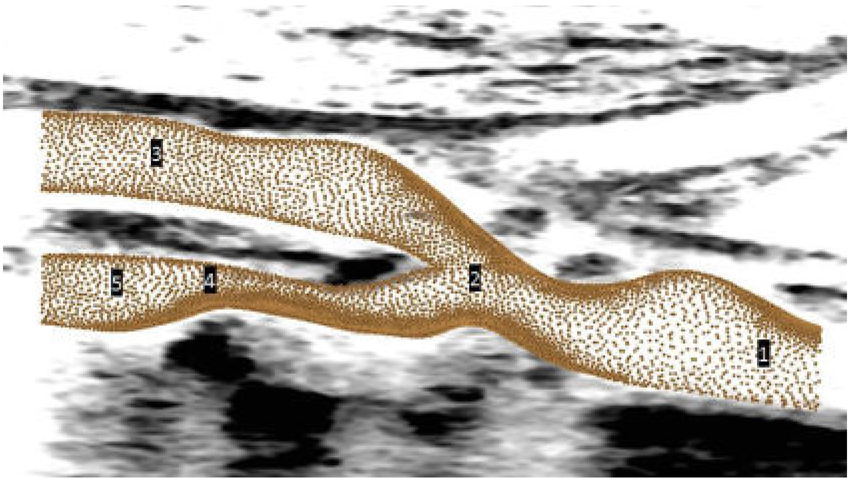

Fig. 3 - Volume discretization of the region of interest superposed on an acquired longitudinal B-mode image and locations of PW Doppler velocity records: (1) distal CCA; (2) bifurcation; (3) distal ECA; (4) stenotic ICA; (5) distal ICA of carotid artery bifurcation.

Recent work on carotid flow simulations considers as input boundary conditions patient-specific pulsatile flow at the common carotid artery with time-varying flow divisions at the two outlets, internal and external carotid, deduced from the envelope of velocities obtained by pulsed Doppler ultrasound (Sousa et al., 2014a). In fact, ultrasound equipment calculates the velocity of blood flow according to the Doppler equation. Since the transmitted ultrasound frequency and the speed of sound in the tissue are assumed to be constant during the Doppler sampling, the Doppler shift frequency is directly proportional to the velocity of red blood cells and the cosine of the Doppler angle. The optimal position of the sample volume box in a normal artery is in the mid lumen parallel to the vessel wall, whereas in a diseased vessel it should be aligned parallel to the direction of blood flow. The analysis of the clinician of the Doppler flow velocity is based on manual identification of some important points, such as the velocity at systolic peak (PSV, peak-systolic velocity) and end-diastole envelope velocity (EDV, end-diastolic velocity). When the lumen of the vessel is narrow, the sample volume catches effectively the whole velocity profile and looking at the wave envelope means looking to the highest velocities reached by the blood flow.

Fig. 4 presents, on the left, a Doppler spectrum of velocities acquired during examination and, on the right, the extracted velocity envelope and superposed periodic signal of the cardiac cycle. The Doppler spectrum of velocities can also be read as a histogram that varies over time. For one specific time of the cardiac cycle, the grey intensities represent the number of red blood cells moving at that specific velocity in the sample volume and, thus, a density of points. From this, the idea of the extraction of statistical indexes at fixed time arises and using those indexes could be a method to reduce propagated uncertainties introduced on a model through boundary conditions.

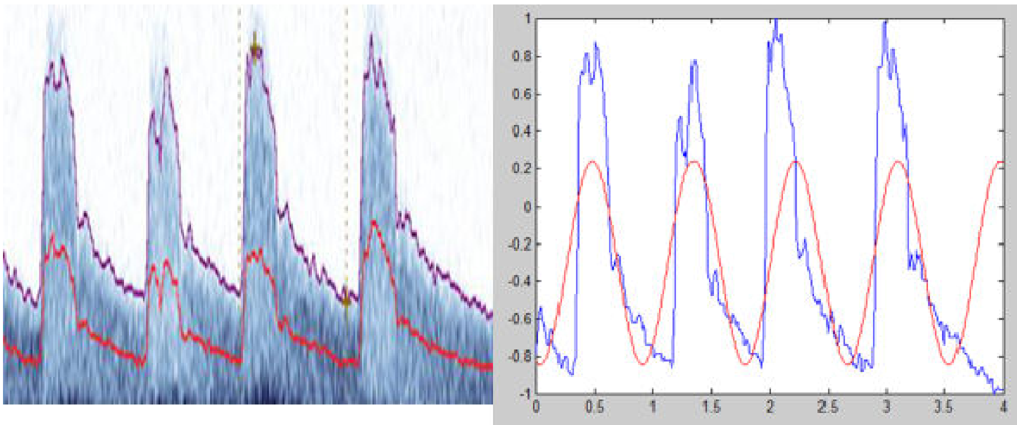

Fig. 4 - Extracted velocity envelope and superposed periodic signal of an acquired PW Doppler ultrasound image

Aiming at obtaining a good representation of the carotid artery blood flow behaviour selected sample volumes at specific locations were considered in the collection of clinical Doppler data in the common, internal and external carotid arteries. Collected data and statistical indexes were used as input/output patterns in ANN learning procedure. The periodicity of the blood flow inside the carotid arteries need not be equal to the frequency of the heartbeat. Acquisitions along the carotid bifurcation were available and blood velocity period at different points of the artery was previously performed.

RESULTS AND CONCLUSIONS

Carotid artery bifurcation of a patient with suspected atherosclerotic disease was evaluated using B mode and PW Doppler ultrasound imaging, acquired by an experienced radiologist exclusively dedicated to neurovascular ultrasound studies at the Neurosonology Unit of the Department of Neurology of Hospital São João, Porto, Portugal. Blood flow was analysed using a patient specific optimal ANN simulator using an input data vector defined by the set of position and time values from Doppler measurements and the corresponding output data vector the envelope spectral Doppler ultrasound signal.

Aiming at obtaining a good representation of the carotid artery hemodynamic behaviour, sample volume PW Doppler was recorded at five different locations of the carotid bifurcation. Locations and PW Doppler records were used as input/output patterns in ANN learning procedure. The optimal ANN assigned a hidden layer of ten nodes and a sigmoid transfer function for the hidden layer and a linear transfer function for the output layer (Castro et al. 2014b).

Features of a severe ICA or CCA stenosis may include the following: PSV greater than 230 cm/sec, a significant amount of visible plaque (≥50% lumen diameter reduction on a grey-scale image), colour aliasing despite a high colour velocity scale setting (≥100 cm/sec), spectral broadening, post-stenosis turbulence at PW Doppler imaging, artefact in the surrounding tissue of the stenotic artery, end-diastolic velocity of greater than 100 cm/sec, ICA/CCA PSV ratio of 4.0 or greater, and finally a high-pitched sound at PW Doppler imaging (Sousa et al., 2014b).

Results obtained from simulation using ANN along longitudinal axes of carotid artery bifurcation are shown in Fig. 5, common/external carotid artery (ECA on the left) and common/internal carotid artery (ICA on the right) for different instants of cardiac cycle. The blood flow behaviour is quite small along the longitudinal axis of common carotid artery and significantly larger towards the distal regions of IC artery. High gradient values denote a possible risk of stroke for this specific patient.

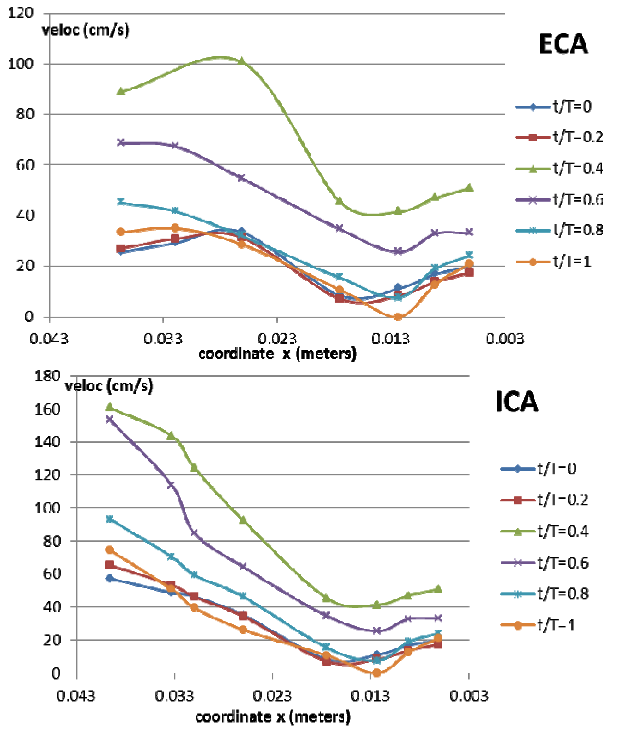

Fig. 5 - Results obtained from simulation using ANN along longitudinal axes of carotid artery bifurcation.

The analysis of anatomically realistic blood flow simulations has the potential to enhance our understanding of how hemodynamic factors are involved in atherosclerotic disease (Sousa et al., 2014c). In the future, we intend to extend the proposed scheme at different types of medical images for effective medical image feature extraction and ANN simulation to show the seriousness of disease. Further, we intend to explore various types of features, which may be used to improve the accuracy of simulation based on ultrasound image analysis.

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REFERENCES

[1]-Castro CF, António CC, Gonçalves JP, Sousa LC. Improving the accuracy of carotid models obtained from ultrasound data. Proceedings CLME'2014 - 7º Congresso Luso-Moçambicano de Engenharia e IVCEM - 4º Congresso de Engenharia de Moçambique, J. F.

Silva Gomes, Clito F. Afonso, Carlos Alberto Conceição António, António S. Matos, 2014a, p.367.

[2]-Castro CF, António CC, Sousa LC, Santos RM, Azevedo E. Near-Optimum Carotid Disease Analysis using Ultrasound Image Data. ECT2014 - The Ninth International Conference on Engineering Computational Technology, B.H.V. Topping, P. Iványi, 2014b.

[3]-Chaudhry A, Hassan M, Khan A, Kim J, Tuan T. Automatic Segmentation and Decision Making of Carotid Artery Ultrasound Images. Intelligent Autonomous Systems 12, Berlin, Springer, 2012, p. 185–196.

[4]-Loizou CP. A review of ultrasound common carotid artery image and video segmentation techniques. Med Biol Engineering and Computing, 2014, 52(12), p. 1073-93.

[5]-Menchón-Lara RM, Bastida-Jumilla MC, Morales-Sánchez J, Sancho-Gómez JL. Automatic detection of the intima-media thickness in ultrasound images of the common carotid artery using neural networks. Med Biol Engineering and Computing, 2014, 52(2), p. 169-81.

[6]-Santhiyakumari N, Madheswaran M. Non-Invasive Evaluation of carotid artery wall thickness using improved dynamic programming technique. Journal of Signal, Image and Video processing, 2008, 2, p. 183-193.

[7]-Santos AMF, Santos RM, Castro PMAC, Azevedo E, Sousa L, Tavares JMRS. A novel automatic algorithm for the segmentation of the lumen of the carotid artery in ultrasound B-mode images. Expert Syst. Appl, 2013, 40(16), p. 6570–6579.

[8]-Sousa LC, Castro CF, António CC, Santos AMF, Santos RM, Castro PMAC, Azevedo E, Tavares JMRS. Haemodynamic conditions of patient-specific carotid bifurcation based on ultrasound imaging. Computer Methods in Biomechanics and Biomedical Engineering: imaging & visualization, 2014a, 2 (3), p.157-166.

[9]-Sousa LC, Castro CF, António CC, Tavares JMRS, Santos AMF, Santos RM, Castro PMAC, Azevedo E. Simulated hemodynamics in human carotid bifurcation based on Doppler ultrasound data. International Journal of Clinical Neurosciences and Mental Health, 2014b, 1, p.7.

[9]-Sousa LC, Castro CF, António CC, Santos AMF, Santos RM, Castro PMAC, Azevedo E, Tavares JMRS. Toward hemodynamic diagnosis of carotid artery stenosis based on ultrasound image data and computational modelling. Med. Biol. Engineering and Computing, 2014c, 52(11), p. 971-983.