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Segmentation of intima media complex from carotid ultrasound images using wind driven optimization technique

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ABSTRACT

Cardiovascular diseases are the third leading cause of death worldwide. The primitive indication of the possible onset of a cardiovascular disease is atherosclerosis, which is the accumulation of plaque on the arterial wall. The intima-media thickness (IMT) of the common carotid artery is an early marker of the development of cardiovascular disease. The computation of the IMT and the delineation of the carotid plaque are significant predictors for the clinical diagnosis of the risk of stroke. For a robust diagnosis, carotid ultrasound images must be free from speckle noise. To address this problem, we use state-of-the-art despeckling and enhancement methods in this work. Many edge-based methods for IMT estimation have been proposed to overcome the limitations of manual segmentation. In this paper, we present a fully automated region-of-interest (ROI) extraction and a threshold-based segmentation of the intima media complex (IMC) using a wind driven optimization (WDO) technique. A quantitative evaluation is carried out on 90 carotid ultrasound images of two different datasets. The obtained results are compared with those of state-of-the-art techniques such as a model-based approach, a dynamic programming method, and a snake segmentation method. The experimental analysis shows that the proposed method is robust in measuring the IMT in carotid ultrasound images.

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1. Introduction

The World Health Organization reported that stroke is one of the common causes of morbidity and mortality worldwide. In a recent survey [50], it was found that 30% of the mortality around the world is due to cardiovascular diseases. The main cause of cardiovascular diseases is atherosclerosis [48], which is the accumulation of plaque on the arterial wall. The incidence of stroke is associated with the rupture of atherosclerotic plaques in the common carotid artery (CCA) [37]. The estimation of the intima-media thickness (IMT) can be used for early atherosclerosis diagnosis that can prevent serious cardiovascular diseases. Fig. 1 illustrates a longitudinal B-mode ultrasound image of the CCA. In the longitudinal view, the CCA can be seen as a dark portion constituting the lumen, which is bound at the top by the near wall and at the bottom by the far wall (Illustrated in Fig. 1). The intima layer is not adequately visible and is often seen with the adventitia layer owing to the poor difference in the acoustic impudence between the two adjacent interfaces. The adventitia layer normally appears as bright gray (highly echogenic), whereas the media layer appears as dark gray (indicated by black arrows at the right side of the image in Fig. 1). The image consists of two semi-parallel traces that constitute the lumen intima (LI) and media adventitia (MA). The IMT of the CCA is the key marker of cardiovascular risk and is computed as the distance between the LI and the MA [45]. The increase in IMT is linearly related to the progression of stroke, which is observed more in the elderly [8,28].

The speckle noise in carotid ultrasound images degrades the quality of the images, which makes the segmentation for measuring the IMT in a carotid wall complex [25]. To overcome this problem, researchers use several methods for preprocessing carotid ultrasound images, using the most common types of filters such as the lee filter [29], frost filter [16], non-local mean filter [9], speckle reduction anisotropic diffusion filter [1], detail-preserving anisotropic diffusion filter [10], and optimized Bayesian least square estimation filter [40]. Generally, the IMT can be manually measured by experts. However, manual tracing is a tedious, unreliable, and time-consuming process. To address this issue, researchers have introduced semiautomated or fully automated region-of-interest (ROI) extraction and edge-based segmentation algorithms for the measurement of the IMT in ultrasound images.

In the past two decades, several algorithms have been presented to segment the intima-media complex (IMC) in ultrasound

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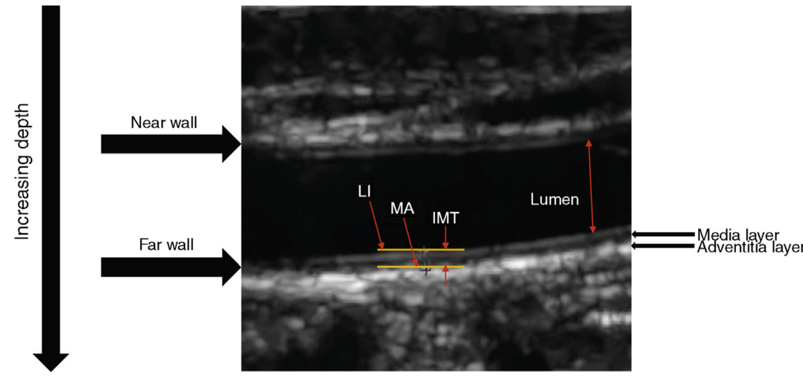

Fig. 1. Illustration of the common carotid artery in longitudinal projection. Drawings on the image taken from [12].

images. Techniques such as the Hough transform [19] have been used to detect the dominant lines in longitudinal carotid ultrasound images. The active contour method [35,34,32,33] has been proposed to segment the IMT of the CCA by integrating different forces in the snake energy function. Frequency domain-based active contours [5,3] have been proposed to provide soft final contours, which are computationally faster than other contour-based methods. A completely automated multi-resolution edge snapper [38] technique recognizes the carotid wall based on the statistical classification in a multi-resolution framework. Dynamic programming [30] has been employed for the detection of echo interfaces using the combined measurement of the echo intensity, boundary continuity, and intensity gradient. The maximum gradient technique [15] has been presented to detect the relative variation in gray levels. The combination of maximum gradient and dynamic programming methods has been applied to detect an instantaneous change in the distribution of the IMT in sequential ultrasound images [43]. The stochastic optimization Bayesian model [14] segments the IMC by considering the dynamic attributes of a tissue such as the elasticity distribution, which is modeled by a mixture of three Nakagami distributions. A model-based [24,23] approach has been used for the automated segmentation of the IMT in carotid ultrasound images, and it deals with the irregularity of the IMC over the cardiac cycle. However, the aforementioned edge-based techniques focus more on the accuracy of the IMT measurement rather than on the robustness. The edge-based techniques use function values and derivatives [52] but do not perform effectively for smooth unimodal problems. In addition, they show poor performance owing to the inconsistencies in the function values. Hence, non-gradient-based algorithms are preferred because they depend only on the function values not on the derivatives. The non-gradient-based techniques include mainly the thresholding methods, which are used for the segmentation of images [2]. Essentially, thresholding utilizes the distribution of the gray levels to distinguish an object from the background. Both the bi-level and the multilevel thresholding techniques require an optimum threshold value to segment the object of interest from its background [22].

In the past few years, numerous thresholding techniques have been proposed with objective functions to obtain the optimal solution. Otsu's [41] technique searches for the threshold that maximizes the variance between classes and minimizes the intra-class variance. Tsallis [47] entropy technique is implemented using the moment-preserving principle to choose the threshold of the gray-level input image. Kapur's [26] entropy is evaluated in determining the threshold values for the minimum intensity gradient in an edge detection algorithm. In previous studies, various works on optimization algorithms using swarm techniques have been introduced, which include the particle swarm optimization (PSO) [36] algorithm. PSO is a swarm-based problematic optimization method that depends on the social behavior of bird flocking to minimize the objective function obtained from the Otsu, Tsallis, and Kapur entropies. The ant colony optimization (ACO) [46] algorithm simulates the behavior of ant colonies. The cuckoo search (CS) [7] algorithm was inspired by the combination of the life of a cuckoo bird and the levy flight behavior of fruit flies, and the artificial bee colony (ABC) [54] algorithm simulates the foraging behavior of bees for multimodal and multidimensional numerical optimization problems. However, all these methods are computationally complex when they are extended to multilevel thresholding methods. To overcome this issue, we use threshold-based segmentation using the wind-driven optimization (WDO) [7] algorithm.

The purpose of this paper study was to develop a more effective strategy, which that can achieve a satisfactory accuracy for IMT measurement with improved robustness to noise. For a robust IMT measurement, a denoising algorithm is applied to the ROI before extracting the efficient features. We propose a fully automated ROI extraction and threshold-based IMC segmentation method using the WDO algorithm. The WDO technique was applied to find the optimal solution for the objective function obtained based on Otsu's thresholding to estimate the IMT. It was observed that the proposed method gives a superior performance when compared to the existing methods. The rest of the paper is organized as follows. Section 2 explains the carotid ultrasound image acquisition and provides a brief description of the existing techniques for segmentation. In Section 3, the proposed methodology is presented in detail. Section 4 compares the results of the proposed method with those of the existing methods. Section 5 describes the experimental analysis and Section 6 presents the conclusion.

2. Materials and methods

2.1. Ultrasound image data acquisition

We used two different datasets: dataset 1 and dataset 2. Dataset 1 consisted of 100 images collected from the Cyprus Institute of Neurology of Nicosia [12]; of these images, 65 were used for this experiment and the remaining 35 were neglected because of their poor visual quality. The images were acquired using an ATL HDI-3000 ultrasound machine used with a linear probe with having a frequency range of 4–7 MHz. The Dataset 2 consisted of 25 images collected from the Father Muller Medical College Hospital, Mangalore, India. These images were acquired using a Philips HD-11 XE ultrasound scanner covering a frequency range of 7–12 MHz. Total Ninety B-mode longitudinal images were used for the performance evaluation of the proposed and existing methods. The images from dataset 1 were captured with a resolution of 768×576 pixels, whereas those of dataset 2 were recorded with a resolution of 800×564 with 256 gray levels, and the images were

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