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Carotid wall segmentation in longitudinal ultrasound images using structured random forest☆

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ABSTRACT

Edge detection is a primary image processing technique used for object detection, data extraction, and image segmentation. Recently, edge-based segmentation using structured classifiers has been receiving increasing attention. The intima media thickness (IMT) of the common carotid artery is mainly used as a primitive indicator for the development of cardiovascular disease. For efficient measurement of the IMT, we propose a fast edge-detection technique based on a structured random forest classifier. The accuracy of IMT measurement is degraded owing to the speckle noise found in carotid ultrasound images. To address this issue, we propose the use of a state-of-the-art denoising method to reduce the speckle noise, followed by an enhancement technique to increase the contrast. Furthermore, we present a novel approach for an automatic region of interest extraction in which a pre-trained structured random forest classifier algorithm is applied for quantifying the IMT. The proposed method exhibits $IMT_{mean} \pm$ standard deviation of 0.66mm ± 0.14, which is closer to the ground truth value 0.67mm ± 0.15 as compared to the state-of-the-art techniques.

1. Introduction

Detection of edges is an important preprocessing stage for several types of tasks, including object detection, image segmentation, and active contouring. Traditional approaches for edge detection make use of a variety of features such as brightness, contrast, gradient, and color [1]. In the past few decades, edge-detection methods have made use of several learning techniques for image segmentation. The learning approaches consider an image patch to estimate the likelihood of the center pixel to determine an edge. Recently, the structured learning approach has been applied to the problem of edge detection [2]. In this paper, we present a structured learning approach to segment the intima media complex (IMC) of the common carotid artery (CCA). In a recent survey, it was found that cardiovascular diseases (CVDs) are the leading cause of mortality in the world. For current lifestyles, prevention is the key to decrease the occurrence of CVDs and thus the number of global deaths. Therefore, an early marker of increased risk of CVD is a significant predictor for clinical diagnoses. Fig. 1 depicts the longitudinal projection of the CCA, which comprises a lumen that is surrounded by a near wall and a far wall. The interface intima is not clearly visible owing to the low contrast of the thin structure. The adventitia and media interfaces appear bright gray and dark gray respectively. The image comprises two semi-parallel traces that constitute the lumen intima (LI) and media adventitia (MA). The intima media thickness (IMT) of the CCA is the key marker of cardiovascular risk

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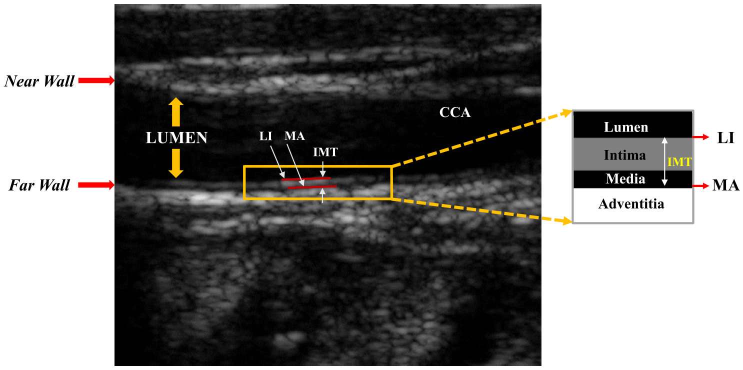

Fig. 1. Illustration of longitudinal projection of the common carotid artery. (Drawings on the image was taken from [3]).

in the carotid wall and is evaluated as the distance between the LI and MA. The increase in the IMT is linearly related to the progression of the stroke, which has been observed to be prevalent in elderly adults. Although several edge-detection algorithms have been proposed for estimating IMT, accurate segmentation remains a challenge [4]. Precise and accurate quantification of IMT of the CCA is important for determining the progression of carotid atherosclerosis and to evaluate the risk of stroke.

Carotid ultrasound images have speckle noise, which degrades the image quality and complicates the measurement of IMT of the carotid wall. In order to address this problem, several despeckling filters have been presented in [5]. These filters require a significant amount of execution time because of their iterative nature. To address this issue, we propose the use of a Weiner filter in the wavelet domain in order to reduce speckle noise in carotid ultrasound images. The adaptive gamma correction (AGC) [6] enhancement technique is then applied to improve the robustness of the proposed method; this is followed by a novel automatic ROI extraction method utilized for segmentation of the IMC. Typically, IMT quantification can be performed manually by medical experts; however, quantification of an IMT via manual delineation is an unreliable and time-consuming process. In order to address this problem, semi- or fully automatic gradient- and non-gradient-based segmentation algorithms have been introduced to facilitate the quantification of IMT of the carotid artery. However, achieving accurate segmentation for IMT measurement remains a challenge. Hence, a novel approach is presented for increasing the accuracy of the segmentation of the IMC. Recently, fast edge detection using learning-based classifiers has been receiving increasing attention. In the past few years, several methods have been implemented using learning-based edge detection techniques [7]. The importance of structure learning approach directly predicts the local structure of the image. Structure learning approach is popular for several reasons: They include its simplicity, fast in training and even faster in testing, resistant to overfitting, and parallel implementation. Hence, we propose the use of a general learning model based on the structured class label of the output spaces. The main contribution of this paper is as follows: (1) we employ a simple and efficient speckle denoising technique followed by gamma enhancement method to aid the precise ROI extraction, (2) we present a novel approach to automatically perform the ROI extraction of the CCA, (3) we propose to use pre-trained structured random forest classifier algorithm which consists a novel data splitting function that exploits the joint distributions observed in the structured label space for learning typical label transitions between object classes.

The paper is organized as follows: Section 2 introduces related works on existing techniques for IMT segmentation. In Section 3, the proposed methodology is presented in detail. Section 4 explains the comprehensive results of the proposed method with respect to the state-of-the-art methods. Section 5 presents a discussion with an experimental analysis. Finally, Section 6 presents the conclusion.

2. Materials and methods

2.1. Dataset description

For our experiment, we used a dataset from the Cyprus Institute of Neurology of Nicosia [3]. The dataset consists of 100 images, of which 70 images are used to evaluate the performance of the proposed and existing methods. The remaining 30 images were ignored because of their poor visual quality. The images were acquired using the ATL HDI 3000 ultrasound machine, which has a frequency range of 4–7 MHz. The frames were captured at a resolution of 564 × 800 pixels and resampled at a standard density of 16.66 pixels/mm. Textual marks were eliminated, and the images were cropped to a size of 395 × 295 pixels.

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