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Fully automatic segmentation of ultrasound common carotid artery images based on machine learning

Rosa-María Menchón-Lara*, José-Luis Sancho-Gómez

Dpto. Tecnologías de la Información y las Comunicaciones, Universidad Politécnica de Cartagena, Plaza del Hospital, 1, 30202 Cartagena, Murcia, Spain

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A B S T R A C T

Atherosclerosis is responsible for a large proportion of cardiovascular diseases (CVD), which are the leading cause of death in the world. The atherosclerotic process is a complex degenerative condition mainly affecting the medium- and large-size arteries, which begins in childhood and may remain unnoticed during decades. It causes thickening and the reduction of elasticity in the blood vessels. An early diagnosis of this condition is crucial to prevent patients from suffering more serious pathologies (heart attacks and strokes). The evaluation of the Intima-Media Thickness (IMT) of the Common Carotid Artery (CCA) in B-mode ultrasound images is considered the most useful tool for the investigation of preclinical atherosclerosis. Usually, it is manually measured by the radiologists. This paper proposes a fully automatic segmentation technique based on Machine Learning and Statistical Pattern Recognition to measure IMT from ultrasound CCA images. The pixels are classified by means of artificial neural networks to identify the IMT boundaries. Moreover, the concepts of Auto-Encoders (AE) and Deep Learning have been included in the classification strategy. The suggested approach is tested on a set of 55 longitudinal ultrasound images of the CCA by comparing the automatic segmentation with four manual tracings.

1. Introduction

Cardiovascular diseases (CVD) represent the major cause of death and disability worldwide. Atherosclerosis is responsible for a large proportion of CVD [1]. It is a chronic degenerative disease characterized by the accumulation of fatty material and cholesterol at the arterial walls. Therefore, atherosclerosis causes thickening and the reduction of elasticity in the arterial walls. Although this pathology may remain unnoticed for decades, atherosclerotic lesions (plaques) could even lead to a total occlusion of the blood vessels. This is the major underlying cause of heart attacks and strokes. For this reason, an early diagnosis and follow up of the atherosclerosis is crucial for preventive purposes. In this sense, the Intima-Media Thickness (IMT) of the Common Carotid Artery (CCA) is considered as an early and reliable indicator of this condition [2].

The IMT is measured by means of a B-mode ultrasound scan, which is a noninvasive , relatively inexpensive, and widely available technique that allows a short time examination. However, resolution and contrast of ultrasound images are generally poor. These images are affected by the multiplicative speckle noise, which tends to reduce the image quality, obscuring and blurring diagnostically important details. The use of different protocols and the variability between observers are recurrent problems in the IMT measurement procedure. Repeatability and reproducibility of the process are of great significance to study the IMT [3,4]. For these reasons, IMT should be measured preferably on the far wall of the CCA within a region free of plaque [2]. The optimal measurement section (1 cm long) is located at least 5 mm below the carotid bifurcation, where a double-line pattern corresponding to the intima-media-adventitia layers can be clearly observed. As can be seen in Fig. 1, the IMT is the distance between the lumen-intima (LI) interface and the media-adventitia (MA) interface.

Usually, delineations of the CCA are manually performed by medical experts. By means of image segmentation algorithms it is possible to reduce the subjectivity and variability of manual approaches and detect the IMT throughout the artery length. In the last two decades, several solutions have been developed to perform the carotid wall segmentation in ultrasound images [5]. Most of the proposed methods are not completely automatic and they require user interaction to start the algorithm, such as [6–10]. However, some fully automatic approaches were recently published [11–15]. It is possible to make a classification of techniques according to the used methodology. In this sense, we can find algorithms based on edge detection and gradient-based techniques [6,8,9,16], and other proposals based on dynamic programming [17–22], active contours [7,12,23–28], neural networks [11] or in a

* Corresponding author.
E-mail address: rmml@alu.upct.es (R.-M. Menchón-Lara).

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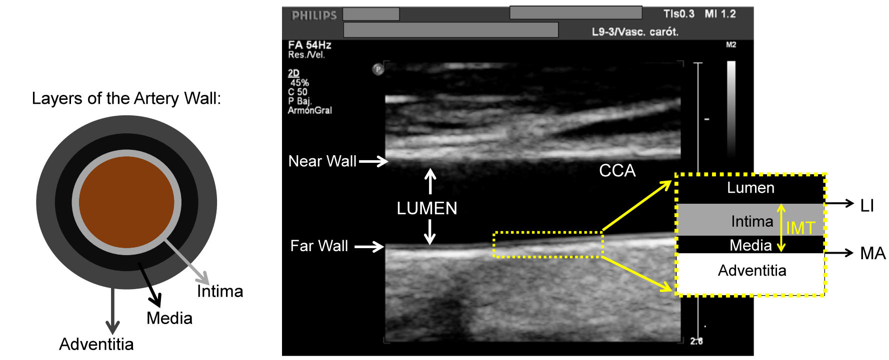

Fig. 1. Diagram of the artery wall (left) and longitudinal view of the CCA in a B-mode ultrasound image (right).

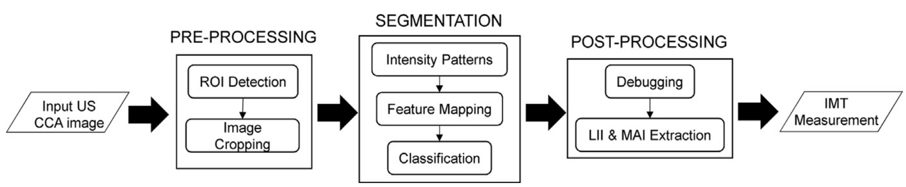

Fig. 2. Overview of the proposed method for carotid wall segmentation and IMT measurement.

combination of techniques [10,29,14]. There are also highlight techniques based in statistical modeling [30,31] or in Hough transform [13,32].

In this work, a fully automatic segmentation technique based on Machine Learning and Statistical Pattern Recognition is proposed to measure IMT from ultrasound CCA images. Firstly, a given image is pre-processed to detect the region of interest (ROI). Then, pixels belonging to the ROI are classified by means of artificial neural networks to identify the LI and MA interfaces. The concepts of Auto-Encoders (AE) and Deep Learning have been included in this classification stage. Finally, the obtained results are post-processed to extract the final contours for the IMT measurement. The automatic measures of the IMT have been compared with the values obtained from different manual segmentations and the statistical analysis of this comparison shows the accuracy of the proposed method.

The remainder of this paper is structured as follows: Section 2.1 describes the dataset of ultrasound CCA images and the manual segmentations. In Section 2.2, the proposed segmentation method is explained in detail. The obtained results are shown in Section 3. Finally, the main extracted conclusions close the paper.

2. Materials and methods

2.1. Ultrasound image acquisition and manual segmentations

A set of 55 longitudinal B-mode ultrasound images of the CCA have been used in this work. All of them were provided by the Radiology Department of *Hospital Universitario Virgen de la Arrixaca* (Murcia, Spain). Fig. 1 (right) shows an example of the tested ultrasound images. Ultrasound scans were acquired using a *Philips iU22 Ultrasound System* by means of three different ultrasound transducers (*L*12-5, *L*9-3 and *L*17-5) and recorded digitally with 256 gray levels. The spatial resolution of the images ranges from 0.033 to 0.066 mm/pixel, with mean and standard deviation equal to 0.051 and 0.015 mm/pixel, respectively. The parameters of the scanner were adjusted in each case by the radiologist. Some blurred and noisy images, affected by intraluminal artifacts, and some others with partially visible boundaries are included in the studied set.

To assess the performance of the proposed segmentation method and the accuracy of the obtained IMT measurements, it is necessary to compare the automatic results with some indication of reference values (*ground-truth*, GT). In this case, the GT corresponds with the average of four different manual segmentations for each ultrasound image. In particular, two experienced radiologists delineated the 55 images twice, with a mean period of two months between tracings. Each manual segmentation of a given ultrasound image includes tracings for the LI and MA interfaces on the far carotid wall.

2.2. Carotid ultrasounds segmentation

Fig. 2 shows an overview of the proposed IMT segmentation methodology. Firstly, a given ultrasound CCA image is pre-processed to automatically detect the region of interest (ROI), which is the far wall of the blood vessel. As result of this stage, a cropping of the input ultrasound image is obtained (ROI image). Then, a windowing process takes place on the ROI image in order to construct the intensity pattern corresponding to each pixel (intensity values from a neighbourhood). After this, different auto-encoders provide compressed representations of these intensity patterns in a lower dimensional feature space. The new features are classified by means of artificial neural networks to separately detect the LI and MA interfaces. Finally, classification results are post-processed to extract the final contours on which the IMT is measured.

2.2.1. Pre-processing of ultrasound CCA images

In the carotid ultrasound images (see Fig. 1), the lumen corresponds to a dark region (low echogenicity) delimited by the arterial walls. Over the lumen in the picture, at less depth, it is observed the echo corresponding to the near wall. The far wall, where the IMT is measured, is located below the lumen, and it constitutes the region of interest (ROI).

The aim of the pre-processing stage is the location of the carotid far wall in a completely automatic way. In particular, a binary mask is built using morphological operations [33] to locate the carotid lumen. Once the lumen has been located, we focus on its lower limit corresponding to the far wall of the CCA and the